JPRS L/10193

16 December 1981

USSR Report

METEOROLOGY AND HYDROLOGY

No. 10, October 1981

FBIS FOREIGN BROADCAST INFORMATION SERVICE

FOR OFFICIAL USE ONLY

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400080048-7

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400080048-7

JPRS L/10193

16 December 1981

USSR REPORT

METEOROLOGY AND HYDROLOGY

No. 10, October 1981

Translations or abstracts of all articles of the Russian-language monthly journal METEOROLOGIYA I GIDROLOGIYA published in Moscow by Gidrometeoizdat.

CONTENTS

* Denotes items which have been abstracted.

* Denotes items which have been abstracted.

UDC 551.524.34(100)

CHANGES IN THE THERMAL REGIME IN THE PHANEROZOIC ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 3 Feb 81) pp 5-10

[Article by M. I. Budyko, corresponding member USSR Academy of Sciences, State Hydrological Institute]

[Abstract] In the study of natural conditions in the past the greatest attention is usually devoted to the last interval of the earth's geological history, the Phanerozoic, which began about 570 million years ago. The problem of the reasons for the considerable difference in the climatic conditions of the main part of the Phanerozoic and present-day climate has only recently been clarified. The matter can be investigated by using the semiempirical theory of the thermal regime of the atmosphere, whose use makes it possible to compute the mean air temperature at the earth's surface and the temperature at different latitudes as a function of the principal climate-forming factors, including the value of the solar constant, albedo and the atmospheric CO_2 concentration. It has been concluded that the warm climatic conditions of the past are attributable for the most part to the higher concentration of CO_2 in atmospheric air. It has been established that the global cooling caused by a decrease in the CO_2 concentration under certain conditions was intensified by an increase in the earth's albedo as a result of an increase in the area of the polar snow and ice cover. Since data are now available on changes in the CO_2 concentration for the entire Phanerozoic, it is possible to make computations of mean air temperature not only for the Cenozoic, but also for earlier time intervals. In such computations it is necessary to take two additional factors into account whose influence on Cenozoic climate was less important. One of these is a change in the solar constant, which as a result of the sun's evolution in the past was less than its present-day value. The second factor is a change in the earth's albedo due to fluctuations in the area of the oceans, whose increase led to some decrease in the albedo of the earth-atmosphere system. The evaluation of the role of these factors makes it possible to conclude that although their influence on mean air temperature was usually less than the influence of fluctuations in CO_2 concentration, in some cases it was not negligible. Accordingly, the author has compiled a table which gives the change in mean air temperature in comparison with the present day for each geological period from the Lower Cambrian to the Pliocene. The presented materials make it clear that the variations in mean air temperature in the Phanerozoic were dependent for the most part on changes in CO_2 concentration and to a lesser degree were dependent on changes in solar radiation and the earth's albedo. Tables 2; references 17: 11 Russian, 6 Western.

UDC 551.465.7+551.509.313

DYNAMIC-STATISTICAL PARAMETERIZATION OF THE PROCESS OF THERMAL EFFECT OF THE OCEAN ON THE ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 28 Jan 81) pp 11-18

[Article by Sh. A. Musayelyan, doctor of physical and mathematical sciences, A. D. Tavadyan and D. B. Shteynbok, candidate of physical and mathematical sciences, USSR Hydrometeorological Scientific Research Institute]

[Text]

Abstract: The authors propose a model of the asynchronous effect of the ocean on the atmosphere. The "thermal memory" of the ocean is parameterized by means of integral allowance for the cloud cover over it. A study was made of the possibility of computing the asynchronous influence function applicable to prediction of two-month anomalies of the heat influx over the European USSR. The results of numerical experiments for computing the asynchronous influence function on the basis of factual data are presented.

In weather formation processes on the earth an important role is played by the ocean. One of the possibilities for studying the influence of the ocean on the atmosphere is mathematical modeling of their interaction on an electronic computer using complex hydrodynamic models. The integration of a nonlinear system of equations in partial derivatives, describing the process of interaction between the atmosphere and ocean, is an extremely complex and time-consuming computational problem. Many physical mechanisms of interaction between the ocean and the atmosphere have not yet been fully clarified and their description in models is approximate. The numerical values of a number of parameters in hydrodynamic models, such as the turbulence coefficients and thermophysical parameters, are known only extremely approximately. Additional hypotheses are used in their stipulation. Among the serious problems we should also include inaccuracy in the stipulation of initial and boundary conditions which are necessary in integrating the equations of the problem and also the inadequate resolution in the models and other errors in numerical solution methods. As a result of the factors enumerated above, at the present time, using models of the indicated type, it is impossible to make a realistic prediction for a time of a week or more. A theoretical analysis of the errors in these models is exceedingly difficult due to their nonlinearity. To be sure, complex hydrodynamic models adequately describing processes of interaction in the earth-atmosphere system must be formulated in the future since only by using them is it possible to describe the entire diversity of the processes transpiring in these media. However, at present it is evidently difficult to hope for quick success when using these models for the purpose of long-range weather forecasting. Therefore, together with investigations for improving complex models it is also necessary to develop other approaches to solution of the long-range weather forecasting problem.

A possible approach to the problem of predicting air temperature for long periods in advance is the use of simpler models of the thermal effect of the ocean on the atmosphere in which a detailed description of a number of physical processes is replaced by their indirect description on the basis of different parameterizations. These parameterizations must reflect the macroscale features, synchronous and asynchronous relationships of processes occurring in the real "ocean-atmosphere" system.

To be sure, on the basis of such models it is impossible to formulate a detailed long-range forecast of meteorological fields, but it is entirely reasonable to attempt to predict individual averaged characteristics of meteorological elements and phenomena for a long time in advance. As such a characteristic, as proposed by Academician G. I. Marchuk [1], it is possible to use the mean value of the monthly or seasonal air temperature anomaly for a fixed region. Without question, such characteristics are very important from the practical point of view. One of the merits of the approach developed in [1] is that the inaccuracy in describing some mechanisms can be partially compensated by including in the model actual information concerning the prehistory of behavior of the ocean and the atmosphere. Here it is desirable to combine hydrodynamic and statistical methods. The application and theoretical analysis of such models was also simpler than for full detailed models. All this is indicative of the high prospects for this approach.

Now we will introduce into consideration a model of the type described above, including an indirect description of the thermal effect of the ocean on the atmosphere and oriented on a long-range forecast of the air temperature anomaly. For a parameterization of the heat flux from the ocean to the atmosphere during the cold half year we will use the fact of presence of asynchronous relationships between air temperature anomalies over the land and cloud cover anomalies over the ocean discovered by one of the authors [2] as a result of processing of a great volume of meteorological data. The physical mechanism of these relationships was described in [3, 4]. In particular, in [4], on the basis of the mentioned asynchronous relationships, a dynamic-statistical approach was proposed for the problem of parameterization of the thermal memory of the ocean, based on use of the heat influx equation. Thus, in accordance with [4], in the model it was assumed that the principal source of heating of the atmosphere in the cold half-year is the heat content of the active layer of the ocean, formed during the elapsed warm half of the year, whereas the cloud cover is a regulator of the thermal effect of the ocean on the atmosphere. This process of heat transfer from the ocean to the atmosphere can be described mathematically using the following simple model for a spherical earth D:

$$\frac{\partial T'(t,\omega)}{\partial t} + \mathbf{V}\nabla T'(t,\omega) - \mu\Delta T'(t,\omega) = \int\limits_{t-\tau_1}^{t-\tau_2}\int\limits_{D_{ok}} \chi(t,t',\omega,\omega')S'(t',\omega')\,d\omega'\,dt' + \varepsilon_2(t,\omega), \tag{1}$$

[OK = ocean]

where S' and T' are anomalies of cloud cover and air temperature respectively; $V = (v_\theta, v_\lambda)$ is horizontal wind velocity; μ is the macroturbulence coefficient (horizontal); ∇ and Δ is the gradient operator and the Laplace operator on a sphere; $\omega = (\theta, \lambda)$, θ is the complement of latitude to $\pi/2$; λ is longitude; $d\omega = \sin\theta d\theta d\lambda$ is an element of the surface of a sphere D; D_{ocean} is the region on the sphere occupied by the ocean; $\chi(t, t', \omega, \omega')$ is an asynchronous influence function characterizing the degree of influence of the cloud cover anomaly at the point $\omega' = (\theta', \lambda')$ over the ocean at the time t' on the change in air temperature at the point $\omega = (\theta, \lambda)$ at the time t ($t > t'$); τ_1 and τ_2 are non-negative numbers (or functions which are dependent on t and ω), determining the time interval in which data on the cloud cover anomaly are taken into account; ε_2 are those nonadiabatic factors which cannot be described by the first term on the right-hand side of formula (1).

With respect to the type of equation (1) it is possible to note the following. The same as in [4], we will use the phenomenological approach to the considered problem and the integral term on the right-hand side of equation (1) is one of the possible methods for parameterization of the heat influx from the ocean to the atmosphere. Henceforth this term will be denoted $\varepsilon_1(t, \omega)$. It follows from the form of ε_1 that it describes the asynchronous relationship observed in nature between the cloud cover over the ocean and temporal change in the air temperature anomaly. (The model (1) with a nonlocal integral interaction operator is new for meteorology). We note that in [6] for the parameterization of the heat influx from the ocean by means of cloud cover use was made of a special case of model (1) obtained from the latter in the absence of a dependence of the function χ on t' and ω', that is, with $\chi = \chi(t, \omega)$. The latter condition means that in [6] the implicit assumption was made that there is an identical role of all regions of the ocean in the formation of air temperature on the continent, which is evidently a significant limitation of the model. However, with use of the model (1) such a limitation is removed. In [5] use is made of a model similar to (1), but for determining the function χ a spectral approach is considered.

Our objective is the use of model (1) for a long-range forecast of the time-averaged air temperature anomaly

$$\overline{T}'_{\Sigma}(\theta, \lambda) = \frac{1}{\tau}\int\limits_{\Sigma} T'(t, \theta, \lambda)\,dt, \tag{2}$$

where $\Sigma = [t_1 - \tau, t_1]$ is the time-averaging interval; τ is the averaging scale.

In order to integrate model (1) it is necessary to know the function $\chi(t, t', \omega, \omega')$, and also τ_1 and τ_2. A determination of the precise form of the spatial-temporal dependence of the asynchronous influence function χ (kernel of the integral operator) is a complex problem. In order to ensure the uniqueness of the solution it is necessary to use not only equation (1), but additional considerations concerning the nature of the χ function. Here we will examine only an approximate method for computing the χ function, using data on the time-averaged fields of temperature anomalies and cloud cover anomalies. This method involves the following.

We will rewrite equation (1) in the form

$$F' = \frac{\partial T'}{\partial t} + V \nabla T' - \mu \Delta T', \tag{3}$$

where $F' = \varepsilon_1 + \varepsilon_2$. We introduce into consideration the grid of points of intersection D^h on the sphere D. We will assume that we have an archives of mean monthly fields of air temperature anomalies, cloud cover anomalies and wind velocity for N years. Then, using difference approximations for the derivatives entering into the right-hand side of formula (3), using the latter it is possible to compute the "actual" mean monthly values of the heat influx anomalies during these same N archival years.

In order to determine the problem of computing the asynchronous influence function χ completely we will impose two natural limitations. The first of these involves the requirement of an approximate periodicity of the function χ in time with a period equal to a year, that is

$$\chi(t + rT_0, t' + rT_0, \omega, \omega') = \chi(t, t', \omega, \omega') \tag{4}$$

with all t, t', ω, ω'. In expression (4) T_0 = 1 year, r is any whole number or zero. Condition (4) means that the nature of the relationship between cloud cover anomalies and the change in the temperature anomaly in different years is approximately one and the same. Here we take into account the assumption made in [4] that the asynchronous influence function of interest to us is quasiuniversal. If this requirement of "universality" of the asynchronous influence function is satisfied, χ can be computed in advance (on the basis of archival data) and then it is possible to use model (1) for the purpose of long-range forecasting of the air temperature anomaly for any year. The second requirement on the χ function is related to the limitations on the "time radius" of influence of cloud cover on temperature, as is also manifested in equation (1) in the form of a finite lower limit in a time interval. Mathematically this condition of finiteness is formulated as follows:

$$\chi(t, t', \omega, \omega') = 0 \quad \text{with } t - t' > \tau_2. \tag{5}$$

Conditions (4) and (5), in combination with formula (3), make possible an approximate computation of the grid values of the χ function. For this we will examine the following approximation of the integral term of interaction ε_1 in model (1):

$$\varepsilon_1^{\tau_1, \tau_2}(t_i, \omega_k) \approx \sum_{t'_j \in \Gamma_{t_i}^{\tau_1, \tau_2}} \sum_{\omega'_l \in D^h_{\text{ok}}} \chi(t_i, t'_j, \omega_k, \omega'_l) S'(t'_j, \omega'_l) \Delta\omega_l \Delta t, \tag{6}$$

where

$$\Gamma_{t_i}^{\tau_1, \tau_2} = |t_i - \tau_2, t_i - \tau_1|;$$

D^k_{ocean} is the totality of points of intersection in the grid D^h entering into the ocean region; Δt is the interval of the quadrature formula for time integration; $\Delta\omega_l$ is the area of the l-th "cell" of the cubature formula for integration in space variables.

We will also represent ε_2 in the following form, whose sense will be clarified below:

$$\varepsilon_2(t_i, \omega_k) = \gamma(t_i, \omega_k) + \sigma(t_i, \omega_k), \tag{7}$$

where γ is a time-periodic function with a period equal to one year; σ is a residual term.

The discrimination of the periodic component γ in formula (7) is related to the following circumstance: even with a zero cloud cover anomaly over the ocean there can be formation of an air temperature differing from the norm over the region of interest to us, associated with other heat transfer processes. The γ function characterizes precisely this "residual" heat influx.

For computing χ we will examine a set of grid quadratic functionals

$$Q^h_{\tau_1, \tau_2}(\chi^h, \gamma^h) = \sum_{t_i \in P_{t_0}} \sum_{\omega_k \in \Omega^h} \{F'(t_i, \omega_k) - \varepsilon_1^{\tau_1, \tau_2}(t_i, \omega_k) - \gamma(t_i, \omega_k)\}^2. \tag{8}$$

Here χ^h and γ^h are the grid values of the χ and γ functions; P_{t_0} is a set $\{t_i\}$ of moments in time such that $t_i = t_0 + r_i T_0$; here T_0 = 1 year, r_i is a whole number or zero; t_0 is a fixed moment in time (or a fixed month), for which we want to determine χ; Ω^h is a grid region where we want to compute the heat influx anomaly.

The χ^h and γ^h values will be found from the condition of a minimum functional $Q^h_{\tau_1,\tau_2}$, also using (4) and (5).

The minimizing of $Q^h_{\tau_1,\tau_2}$ means that the asynchronous influence function χ is determined by the best mean square approximation of the actual heat influx anomaly. Determining the $\chi^h_{\tau_1,\tau_2}$ and $\gamma^h_{\tau_1,\tau_2}$ values for different τ_1 and τ_2, we find such τ_{10} and τ_{20} that

$$Q^h_{\tau_{10}, \tau_{20}}(\chi^h_{\tau_{10}, \tau_{20}}, \gamma^h_{\tau_{10}, \tau_{20}}) = \min_{\tau_1, \tau_2} \{Q^h_{\tau_1, \tau_2}(\chi^h_{\tau_1, \tau_2}, \gamma^h_{\tau_1, \tau_2})\}. \tag{9}$$

Then, evidently, the asynchronous function $\chi^h_{\tau_{10},\tau_{20}}(t, t', \omega, \omega')$ (together with $\gamma^h_{\tau_{10},\tau_{20}}(t, t', \omega, \omega')$) will be the best approximation of the heat influx anomaly in model (1).

Now we will proceed to a description of the numerical experiments carried out for practical realization of the dynamic-statistical parameterization method described above.

We are interested in computation of the asynchronous influence function for predicting the winter air temperature anomaly for the European USSR. We had at our disposal archives of data on the mean monthly fields of the cloud cover anomaly and the air temperature anomaly in the lower half of the troposphere at the points of intersection of a geographical grid measuring 5 x 10° in the northern hemisphere for 1965-1967 and 1970-1974. Using archival data and formula (3) we computed the actual heat influx anomalies averaged for two successive months. Use was made of nondivergent wind velocity obtained by solution of the linear balance equation using climatic data on geopotential at the mean level of the atmosphere. The approximation of the space and time derivatives in formula (3) is similar to that set forth in [7]. Below we present the determined actual values of the heat influx anomaly, averaged for November-December and relating to the point ω_0, located approximately 100 km from Moscow.

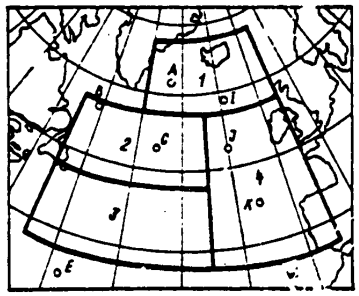

Fig. 1. Ocean regions used in computing the asynchronous influence function.

Data on the anomaly of total quantity of clouds were taken into account in our experiments only over the waters of the North Atlantic, which was divided into four regions, as indicated in Fig. 1. We computed the grid asynchronous influence function for the cloud cover anomaly over each of these regions relative to the formation of the heat influx anomaly in November-December at the point ω_0. The averaged heat influx anomaly, in accordance with what has been stated above, will have the following form:

$$\bar{F}_n^{XI-XII}(\omega_0) = \sum_{l=1}^{4} \bar{\gamma}_l^{XI-XII;j}(\omega_0)\bar{S}_n^{'j}(\omega_l) + \gamma^{XI-XII;j}(\omega_0). \qquad (10)$$

Here l is the number of the region of the Atlantic; ω_l is the central point of the l-th region; n is the number of the year; j is the number of the month (or months) during which cloud cover is taken into account; $\bar{\gamma}_l^{XI-XII;j}(\omega_0)$ is the grid function of the asynchronous influence of the cloud cover anomaly over the l-th region of the Atlantic in the j-th month on the formation of the heat influx anomaly averaged for November-December at the point ω_0 (multiplied by $\Delta\omega_l\Delta t$); $\bar{S}'^{j}_{n}(\omega_0)$ is the cloud cover anomaly averaged for the region l in the j-th month of the n-th year; $\gamma^{XI-XII;j}(\omega_0)$ is the heat influx anomaly averaged for November-December at the point ω_0 with a zero cloud cover anomaly over the Atlantic in the j-th month.

Actual Values of Heat Influx Anomaly, Averaged for November-December, at Point ω_0 (in 10^{-5}°C/sec)

Years	1965	1966	1967	1970	1971	1972	1973	1974
Heat influx value	-1.6	0.1	-1.7	0.8	-0.3	-1.1	2.3	-0.4

We carried out different variants of computations of the γ function differing from one another with respect to the initial data on temperature and cloud cover, that is, with respect to the sample used. A list of the variants is given in Table 1. This table shows that for computing the asynchronous influence function, for example, for the first variant, in the functional (8) it is necessary to use a sample of data on the temperature and cloud cover anomalies for 1965, 1967, 1970, 1972, 1973 and 1974.

Table 1

Variants of Numerical Experiments for Computing Asynchronous Influence Function

No of variant	Years included in sample					
1	1965	1967	1970	1972	1973	1974
2	1966	1967	1970	1971	1973	1974
3	1965	1966	1967	1970	1971	1972
4	1965	1967	1970	1971	1972	1974
5	1965	1966	1971	1972	1973	1974
6	1966	1967	1971	1972	1973	1974

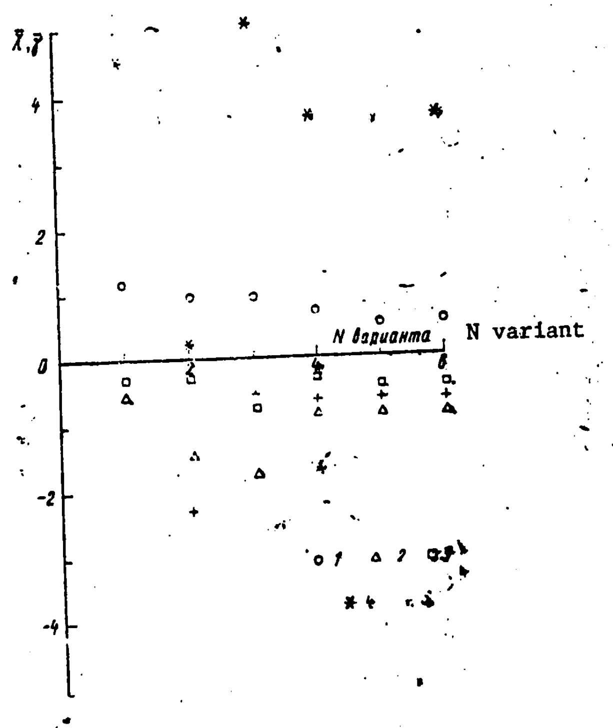

Fig. 2. Values of asynchronous influence function $\overline{\chi}_i^{XI-XII;VI}(\omega_0)$ (in 10^{-5}°C/(sec·unit)) for four regions of ocean and values of the function $\overline{\gamma}^{XI-XII:VI}(\omega_0)$ (in 10^{-5}°C/sec), obtained in different variants of numerical experiments. 1) $\overline{\chi}_1$; 2) $\overline{\chi}_2$; 3) $\overline{\chi}_3$; 4) $\overline{\chi}_4$; 5) $\overline{\gamma}$.

In computing the values of the grid asynchronous influence function $\overline{\chi}^{XI-XII;VI}$ we used the June cloud cover anomaly over the Atlantic, that is, we examined a case when in the model (1) the $\tau_2 - \tau_1$ difference is one month. Figure 2 shows that the values of the function $\bar{\chi}^{XI-XII;VI}$ for the corresponding regions of the ocean are close, especially for regions from the first to the third. The established fact confirms the assumption made above concerning the universal nature of the χ function (see (4)) and indicates a strong asynchronous correlation of the June cloud cover anomaly over the first, second and third regions of the Atlantic with a heat influx anomaly at the point ω_0 averaged for November-December. The component $\bar{\chi}^{XI-XII:VI}$ has a more unstable character. The variability of $\bar{\chi}^{XI-XII:VI}$ evidently indicates a diversity of the physical processes forming the heat influxes over the European USSR in November-December. We also note that the values of the χ function for regions 2 and 3 were negative, which corresponds to the results in [4].

Table 2

Anomaly of Heat Influx for November-December at Point ω_0, Computed Using the Asynchronous Influence Function $\bar{\chi}^{XI-XII;VI}$ (in 10^{-5}°C/sec)

No of variant	Years							
	1965	1966	1967	1970	1971	1972	1973	1974
1	−1,5	0,1	−1,8	0,8	−0,2	−1,1	2,3	−0,4
2	−1,5	0,2	−1,6	0,5	−0,4	−1,2	2,4	−0,4
3	−1,6	0,1	−1,8	0,8	−0,3	−1,1	4,2	−0,8
4	−1,7	−2,9	−1,7	−1,8	−2,4	−3,2	−0,2	−3,6
5	−1,8	0,1	−1,7	0,3	−0,4	−1,1	2,3	−0,4
6	−1,6	0,1	−1,7	0,3	−0,4	−1,1	2,3	−0,4

Using the determined asynchronous influence function $\bar{\chi}^{XI-XII;VI}$ we carried out computations (diagnosis and prediction on the basis of independent data) of the heat influx anomalies themselves in November-December at the point ω_0 using formula (10). Table 2 gives the results of these computations. Some of the values in this table represent the result of prediction, whereas the others represent diagnosis. For example, the data in Table 2, corresponding to 1965, are (see Table 1) prognostic in computations under the second and sixth variants; corresponding to 1966 -- for the first and fourth variants, etc. It can be seen that both the diagnostic and prognostic values for the heat influx anomaly are close to their actual values (presented above) for all variants except the fourth. In general, however, the guaranteed probability of a forecast of the sign of the heat influx anomaly at the point ω_0, averaged for November-December, is approximately 83% according to the data in Table 2.

We carried out numerical experiments similar to those described above for computing the asynchronous influence function and diagnosis and prediction of the heat influx anomaly with use of the summer cloud cover for other summer months. They also confirmed the desirability of introducing universal asynchronous influence functions for predicting the heat influx anomaly. Later we plan to examine different cases of temporal and spatial averaging, investigate the role of circulation in computations of χ and use of the resulting asynchronous influence functions for the long-range forecasting of the air temperature anomaly in model (1).

BIBLIOGRAPHY

1. Marchuk, G. I., CHISLENNYYE RESHENIYA ZADACH DINAMIKI ATMOSFERY I OKEANA (Numerical Solutions of Problems in Dynamics of the Atmosphere and Ocean), Leningrad, Gidrometeoizdat, 1974.

2. Marchuk, G. I. and Musayelyan, Sh. A., "Method for Computing Variations of the Total Flux of Radiant Energy for the Purpose of Long-Range Forecasting of Macroscale Meteorological Fields," METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 8, 1974.

3. Musayelyan, Sh. A., "Problem of Parameterization of the Process of Transfer of Radiant Energy of the Sun in the Ocean-Atmosphere System and Long-Range Forecasting," METEOROLOGIYA I GIDROLOGIYA, No 10, 1974.

4. Musayelyan, Sh. A., O PRIRODE NEKOTORYKH SVERKHDLITEL'NYKH ATMOSFERNYKH PROTSESSOV (Nature of Some Superlong Atmospheric Processes), Leningrad, Gidrometeoizdat, 1978.

5. Musayelyan, Sh. A., Tavadyan, A. D. and Chechetkina, Ye. M., "One Method for Parameterization of the Process of Macroscale Effect of the Ocean on the Atmosphere," TRUDY GIDROMETTSENTRA SSSR (Transactions of the USSR Hydrometeorological Center), No 204, 1978.

6. Sadokov, V. P. and Shteynbok, D. B., "Computation of the Temperature Anomaly of the Troposphere by the Conjugate Equations Method Using Cloud Cover Data," TRUDY GIDROMETTSENTRA SSSR, No 222, 1980.

7. Shteynbok, D. B., "Use of Conjugate Equations for Studying the Formation and Computing the Anomaly of Mean Tropospheric Temperature," Author's Summary of Dissertation for Award of the Academic Degree of Candidate of Physical and Mathematical Sciences, Moscow, Gidromettsentr SSSR, 1979.

UDC 551.510.42

SCATTERING AND TRANSPORT OF A POLLUTANT CLOUD IN THE TROPOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 17 Feb 81) pp 19-25

[Article by V. P. Gavrilov, candidate of physical and mathematical sciences, and A. A. Kostrikov, Institute of Experimental Meteorology]

[Text]

Abstract: On the basis of a semiempirical equation of turbulent diffusion of a parabolic type the authors formulated a model of scattering of a pollutant cloud in the troposphere. Using the moments method it was possible to obtain a closed system of equations describing the behavior of the coordinates of the center of gravity and dispersions of a cloud of passive impurity from an instantaneous source. In the model use is made of the hypothesis of a dependence of the coefficients of horizontal diffusion on the corresponding dispersions (dimensions) of the cloud. Analytical formulas describing the behavior of the center of gravity trajectory are derived for the horizontal components of wind velocity, linearly dependent on altitude, and the constant coefficient of vertical diffusion. Nonlinear equations for dispersions in which the coefficients of horizontal diffusion are proportional to the dispersions in the power 2/3 were solved numerically. The dependence of the horizontal dispersions on the dimensionless number characteristic for the problem is examined. Also discussed is the problem of computation of the distribution of the field of concentration of the impurity and an evaluation is made of the assumption of the normalcy of distribution of this field for the special case considered in the article.

In order to solve many practical problems, such as the tracking of the propagation of accidental industrial effluent over great distances and a number of other problems it is necessary to be able to compute the atmospheric behavior of a cloud of pollutant having small initial dimensions. In most cases it is necessary to know the trajectory of the cloud and the distribution of the concentration in it at different moments in time, including ten hours after the moment of its formation, and not only near the earth's surface, but also in the troposphere.

The problems involved in the turbulent diffusion of a passive pollutant have been relatively well studied theoretically and experimentally for the case of the surface layer of the atmosphere and have been studied less well for the boundary layer and very poorly for the higher layers of the atmosphere. An analysis of the present status of work on atmospheric diffusion can be found in monographs and review articles, such as in [6, 7, 12, 15, 17].

As the mathematical model of the process of transfer and scattering of a cloud of pollutant in the troposphere we will use the widely employed semiempirical equation of a parabolic type

$$\frac{\partial q}{\partial t} + v_i \frac{\partial q}{\partial x_i} = \frac{\partial}{\partial x_i}\left(K_{ij} \frac{\partial q}{\partial x_j}\right), \tag{1}$$

where q is the pollutant concentration, v_i are the wind velocity components, K_{ij} is the tensor of the diffusion coefficients, i, j = 1, 2, 3.

The stipulation of the functional form of the coefficients in equation (1) is a significant, if not the fundamental difficulty in this description of scattering of a pollutant in the turbulent atmosphere. Accordingly, we will first examine the problem of the presence (collection) of information pertaining to the velocity vector v_i and the tensor K_{ij}.

No fundamental difficulties arise in determining the wind velocity vector v_i; the only difficulty may be a shortage of factual information. In the solution of the problems of transport of a pollutant over great distances in a general case the vector v_i must be stipulated as dependent on time and coordinates in connection with the spatial inhomogeneity and temporal evolution of the velocity field. For solving the problem of the behavior of a cloud of pollutant during some time interval in the past (diagnostic problem) it is necessary to have information on the wind velocity field, obtaining it from data from standard radiosonde observations, using interpolation at the point where the cloud is situated. The vertical component can be determined from the field of horizontal velocity, for this purpose using the continuity equation. Existing routine methods for weather forecasting make it possible to obtain prognostic information on the three-dimensional field of wind velocities [1].

The choice of the functional form of the diffusion coefficients involves considerable difficulties because they cannot be unambiguously related to the characteristics of atmospheric turbulence.

According to modern concepts, the scattering of a cloud (increase in its dimensions) occurs under the influence of turbulent eddies whose size is comparable to the size of the cloud of pollutant or smaller than this size. This means that for the cloud the coefficient of turbulent diffusion (which is determined as the rate of increase in its dispersion) is also dependent on the size of the cloud until this size is substantially greater than the size of eddies with a maximum energy, that is, the external turbulence scale. A coefficient specifically dependent on the size of the cloud must also be used in equation (1) for computing the evolution of a cloud from an instantaneous source [2, 3, 7, 15, 17].

In choosing the components of the K_{ij} tensor for specific problems it is necessary to take into account the anisotropy of atmospheric turbulence. Since in the troposphere the spectrum of vertical fluctuations of wind velocity has a maximum in the microscale range, a cloud with a small initial vertical dimension rather rapidly attains such a size that the vertical diffusion coefficient K_{33} will not increase with a growth of the cloud and will be determined by the intensity of the eddies with the maximum energy. Precisely for this reason the vertical diffusion coefficient is assumed to be either constant with altitude or the troposphere is broken down vertically into layers with different behavior of K_{33} in each layer [4, 13, 16].

The maximum in the spectrum of horizontal wind velocity fluctuations is in a region of considerably greater scales -- in the synoptic region [20] and therefore the tensor components $K_{\lambda\lambda}$ responsible for horizontal scattering must be related to cloud size. We note that in turn the horizontal dimensions of the cloud are influenced by both the value of the horizontal diffusion coefficient and the effect of the joint influence of wind velocity shear and vertical diffusion. The contribution of the latter to horizontal scattering can be substantial [7, 8, 11, 14, 18]. In a number of models this complex dependence is simplified by means of a priori stipulation of the dependence of the $K_{\lambda\lambda}$ coefficients on diffusion time (the time from the moment of cloud formation) [13, 16], or, which is the equivalent under the condition of satisfaction of the Taylor hypothesis, on the distance to the source [17].

In this article we propose the direct use of the dependence of the horizontal diffusion coefficient on the horizontal dimension of the cloud.

The nondiagonal components of the tensor K_{ij} are assumed to be equal to zero; the latter means that we use the hypothesis of a nondependence of horizontal diffusion on vertical diffusion.

The specific meteorological conditions will determine the specific dependence of the horizontal diffusion coefficients on cloud size. In particular, there are definite indications that in the range from microscales to tens and even hundreds of kilometers this dependence has a power-law character with an exponent 4/3 [9, 19, 20]. In this article we employ two variants of writing of the dependence of $K_{\lambda\lambda}$ on cloud scale $D^{1/2}_{\lambda\lambda}$:

$$K_{\lambda\lambda} = \begin{cases} c\,\varepsilon^{1/3} D_{\lambda\lambda}^{2/3} & \text{(2a)} \\ c\,\varepsilon^{1/3} (D_{11} D_{22})^{1/3}, \quad \lambda = 1, 2, & \text{(2b)} \end{cases}$$

where c is constant (for numerical computations, see below, we used the value c = 0.1), ε is the velocity of cascade transfer of energy through the spectrum, $D_{\lambda\lambda}$ are the horizontal dispersions of the cloud of pollutant.

The mean velocity of cascade energy transfer can be obtained from information on the wind velocity field [5].

The second variant of the dependence (2b) appears to be physically more valid because numerous experimental investigations in the free atmosphere [20] show that the micro- and mesoscale horizontal disturbances of wind velocity are virtually isotropic. Nevertheless, the problem of how significantly the deviations from isotropicity are reflected in the scattering of a cloud of pollutant in the troposphere for the time being remains open.

At first glance the problem is greatly complicated since the horizontal diffusion coefficients are functions of the dispersions, which in turn are determined through the field of concentration, that is, with such coefficients equation (1) will be nonlinear.

The experimental method and technique of diffusion experiments at the present time do not make it possible to speak of obtaining a detailed experimental distribution of the field of concentration of a pollutant. The dispersions of clouds and plumes of pollutant are measured relatively reliably and precisely, as are the trajectories of movement of the center of gravity of a pollutant cloud. Accordingly, it is more logical to derive equations directly for determining the simplest diffusion characteristics of the pollutant cloud and not extract them from the distribution function. This method, the so-called moments method, has been repeatedly used in examining the diffusion process [11, 14, 18].

Now we will examine the behavior of a cloud of passive pollutant from an instantaneous point source. We will integrate equation (1) for x_1 and x_2, first multiplying it by $x_1^m x_2^n$ (m, n = 0, 1, 2) and limiting ourselves to the case when v_i and K_{ii} are not dependent on the horizontal coordinates, but $v_3 = 0$. As a result, we obtain a system of five equations:

$$\frac{\partial q_0}{\partial t} - \frac{\partial}{\partial z}\left(K_{33}\frac{\partial q_0}{\partial z}\right) = 0, \tag{3}$$

$$\frac{\partial q_\lambda}{\partial t} - \frac{\partial}{\partial z}\left(K_{33}\frac{\partial q_\lambda}{\partial z}\right) = v_\lambda q_0(z, t), \tag{4}$$

$$\frac{\partial q_{\lambda\lambda}}{\partial t} - \frac{\partial}{\partial z}\left(K_{33}\frac{\partial q_{\lambda\lambda}}{\partial z}\right) = 2K_{\lambda\lambda}q_0 + 2v_\lambda q_\lambda, \tag{5}$$

where

$$q_{\lambda\mu}(z, t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_\lambda^m x_\mu^n q(x, y, z, t)\,dx\,dy,$$

$$\lambda, \mu = 1, 2; \quad m, n = 0, 1, 2$$

are the moments ($l = m + n$) of the order (not greater than the second) of the concentration distribution function. Through these moments we determine the central moments of the second order -- the dispersions; then the horizontal diffusion coefficients will have the form

$$K_{\lambda\lambda} = c\,\varepsilon^{1/3}\left[\frac{q_{\lambda\lambda}}{q_0} - \left(\frac{q_\lambda}{q_0}\right)^2\right]^{2/3}, \tag{6a}$$

$$K_{\lambda\lambda} = c\,\varepsilon^{1/3}\left\{\left[\frac{q_{11}}{q_0} - \left(\frac{q_1}{q_0}\right)^2\right]\left[\frac{q_{22}}{q_0} - \left(\frac{q_2}{q_0}\right)^2\right]\right\}^{1/3}. \tag{6b}$$

Now we will examine a specific case when the pollutant is propagated from a high (x, $y = 0$, $z = h$) instantaneous point source, $K_{33} = k = \text{const}$, $\varepsilon = \text{const}$, $v_\lambda = v^0 + \gamma_\lambda(z - h)$. The boundary conditions for the moments are found from the ordinary conditions for the concentration — with the concentration tending to zero at infinity and with absence of a flow at the underlying surface. With these simplifications it is easy to obtain an analytical solution for q_0 and q_λ, describing the behavior of the integral concentration $q_0(z,t)$ vertically and the coordinates of the center of the pollutant cloud $X_\lambda = q_\lambda / q_0$

$$q_0(z,\ t) = \frac{1}{2\sqrt{\pi kt}}\left[e^{-\frac{(z+h)^2}{4kt}} + e^{-\frac{(z-h)^2}{4kt}}\right], \tag{7}$$

$$X_\lambda = (v_\lambda^0 - \gamma_\lambda h)\,t + \frac{\gamma_\lambda}{4}\sqrt{\frac{\pi t}{k}}\times$$

$$\times\left[\frac{(z^2 - h^2 + 2kt)\,\mathrm{erfc}\left(\frac{z+h}{2\sqrt{kt}}\right) + 2(z+h)\sqrt{\frac{kt}{\pi}}\,e^{-\frac{(z-h)^2}{4kt}}}{e^{-\frac{(z+h)^2}{4kt}} + e^{-\frac{(z-h)^2}{4kt}}}\right], \tag{8}$$

where

$$\mathrm{erfc}\,(x) = 1 - \frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}\,dx.$$

Expressions (8) for the coordinates of the center of gravity of the pollutant cloud differ from the corresponding formulas derived in [18] in an examination of diffusion from a surface point source with a linear wind profile and $K_{33} = \text{const}$, $K_{11} = \text{const}$ (or $K_{11}^* z$) in that in (8) the height of the source is taken into account. With $h = 0$ formulas (8) undergo transition into the formulas in [18].

As indicated by the computations, with large z and h and relatively short diffusion times ($z, h \gg \sqrt{kt}$) the curves (8) for X_λ are approximated well by the asymptotic straight line

$$X_\lambda = \left(v_\lambda^0 + \gamma_\lambda\,\frac{z-h}{2}\right)t, \tag{9}$$

which can be used in approximate computations of the trajectory of the center of gravity of a diffusing cloud of pollutant.

The last two equations (5) in the system, describing the behavior of the second moments and accordingly the horizontal dispersions of the cloud of pollutant, are nonlinear and therefore are not subject to analytical solution. For a numerical solution we will reduce the equations to a dimensionless form and we will assume that the initial distribution in the cloud is Gaussian and $v_2 = 0$. We will use the following scales: Q is the mass of pollutant introduced into the atmosphere; U is the scale of wind velocity; $T = U/\varepsilon$ is the time scale; $Z_k = (kT)^{1/2} = U(k/\varepsilon)^{1/2}$ is the height scale; $L = UT = U^2/\varepsilon$ is the length scale. It is found that k and ε will not enter into equations (3)-(5), whereas the expression for dimensionless wind velocity $V_1 = V^1 + G\,(z' - h')$ will include the dimensionless parameter

$$G = \gamma_1 \left(\frac{k}{\varepsilon}\right)^{1/2}, \tag{10}$$

which is the ratio of the diffusion height scale $Z_k = (kT)^{1/2}$, found relative to gradient height scale $Z_\gamma = U/\gamma_1$ (with $\gamma_1 = 10^{-3}$ sec^{-1}, k = 10 m^2/sec and $\varepsilon = 5 \cdot 10^{-4}$ m^2/sec^3, G = 0.14). The parameters forming the number $G = G(\gamma_1, k, \varepsilon)$ in principle are correlated and therefore, despite the fact that we know the limits of change of these parameters, it is difficult to say what G values are observable in the atmosphere.

The equations (3)-(5), reduced to dimensionless form, were solved by the finite differences method. For approximating the equations we used a Crank-Nicholson scheme having a second order of approximation in space and time. The trial-and-error method with iterations was used in solving the derived difference equations [10].

The correctness of application of the finite-difference scheme was checked by a comparison of the numerical solution with the analytical solution (7) and an analytical expression for the horizontal dispersions relative to the center of gravity of the cloud of pollutant:

$$D_{\lambda\lambda} = \left(D_0^{1/3} + \frac{2}{3} c\, \varepsilon^{1/3} t\right)^3, \tag{11}$$

which was obtained from solution of equation (5) with k = 0 and with $K_{\lambda\lambda}$ in the form (2a).

Numerical experiments were carried out for determining the dependence of the horizontal dispersion of the cloud on the dimensionless number G characterizing the joint influence of the wind velocity shear and vertical diffusion on the horizontal scattering. In these experiments the pollutant "was introduced" so high above the underlying surface and such diffusion times were considered that the horizontal dispersion was virtually not dependent on height. The figure (a,b) shows curves of change in dimensionless longitudinal and transverse dispersions when the initial size of the cloud no longer exerts an influence on the behavior of dispersion.

As might be expected, in all the experiments the horizontal dispersion already with relatively short times ($t' \sim 0.07$) increases as t'^3. It can be seen from this same figure that the coefficient on t'^3 is essentially dependent on G. In addition, with the stipulation of $K_{\lambda\lambda}$ in the form (2b) the transverse dispersion is also dependent on G.

If G = 0.14 is used as the characteristic value, then, comparing the horizontal dispersions obtained in the model [13, 16] and from solution of equations (3)-(5) we see that the longitudinal dispersion is greater by a factor of approximately 15 (with stipulation of $K_{\lambda\lambda}$ in the form (2a)) and by a factor of 4 (with $K_{\lambda\lambda}$ in the form (2b)) than the cloud dispersion in the absence of wind shear. Thus, the model in [13, 16] understates the longitudinal dispersion value by several times.

The different stipulation of the functional form of the horizontal coefficients $K_{\lambda\lambda}$ in the form (2a), (2b) leads, beginning with relatively large G values (of about 10^{-2}), to an appreciable difference in the ratios of the horizontal dispersions D_{11}/D_{22} for a given G (see figure c). The figure shows that for large G values the ratios D_{11}/D_{22} increase in the first variant (2a) of stipulation of $K_{\lambda\lambda}$ as G^2, in the second variant -- as G. An answer to the question as to what variant of the behavior of $D_{\lambda\lambda}$ is observable in the atmosphere can be obtained only by a field experiment.

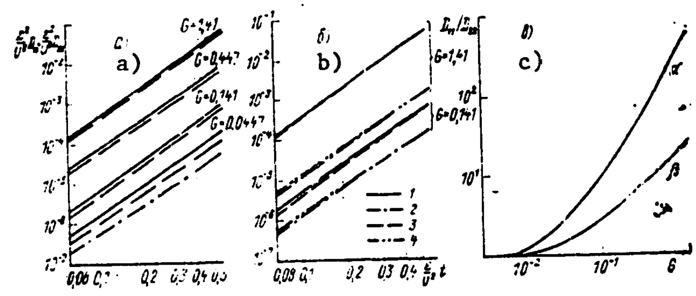

Fig. 1. Dependence of horizontal dispersion of pollutant cloud on time with different values of the G number, $V'_1 = V_1^0 + G(z' - h')$, where $V_1^0 = 10$ m/sec, h = 5000 m, $V_2 = 0$, $D_0 = 5000$ m^2. a) $KK_{\lambda\lambda} = c\varepsilon^{1/3} D^{2/3}$; b) $K_{\lambda\lambda} = c\varepsilon^{1/3}(D_{11}D_{22})^{1/3}$; 1 and 2 -- longitudinal and transverse dispersions obtained as a result of computations using model; 3) longitudinal dispersion computed using formula (12); 4) transverse dispersion computed using formula (13); c) ratio of dispersions D_{11}/D_{22} as function of G number; a) $K_{\lambda\lambda} = c\varepsilon^{1/3}D^{2/3}$, b) $K_{\lambda\lambda} = c\varepsilon^{1/3}(D_{11}D_{22})^{1/3}$.

For many problems information on the behavior of the first two moments of the distribution function for the mean concentration is entirely adequate. In addition, in case of necessity it is possible to write equations for the higher moments and solve them, determining asymmetry, excess and other characteristics of the pollutant cloud. But for some practical problems it is necessary to have evaluations of the mean concentration distribution. A necessary condition for the horizontal distribution to be Gaussian is that the asymmetry and excess coefficients be equal to zero.

As is well known, the third moment of the Gaussian distribution is expressed through the lower moments in the following way:

$$q_{\lambda\lambda\lambda}(z, t) = 3\frac{q_\lambda q_{\lambda\lambda}}{q_0} - 2q_0\left(\frac{q_\lambda}{q_0}\right)^3. \qquad (12)$$

Substituting this expression into the equation for the third moment

$$\frac{\partial q_{\lambda\lambda\lambda}}{\partial t} - \frac{\partial}{\partial z}\left(K_{33}\frac{\partial q_{\lambda\lambda\lambda}}{\partial z}\right) = 6K_{\lambda\lambda}q_0X_\lambda + 3q_{\lambda\lambda}v_\lambda, \qquad (13)$$

we see that the equation is not identically satisfied; on the right-hand side is the additional term

$$6K_{33}q_n \frac{\partial X_\lambda}{\partial z} \frac{\partial D_{\lambda\lambda}}{\partial z}.$$

Thus, the distribution of pollutant becomes asymmetrical if this term is different from zero. Since in the real atmosphere there is virtually always a wind shear, the gradient $\partial X_\lambda / \partial z$ is virtually always different from zero. At the same time, as indicated by our numerical experiments, the dispersion gradient $\partial D_{\lambda\lambda} / \partial z$ is equal to zero with a linear wind velocity profile and only near the lower boundary becomes different from zero. A similar, but externally more complex result is obtained for the fourth moment. Thus, if the initial distribution of the pollutant is Gaussian, the cloud moves distant from the underlying surface and the wind velocity changes virtually linearly with altitude, the distribution of the pollutant at a given level in a cloud within the framework of this model can also be considered normal.

In conclusion the authors express appreciation to N. L. Byzova for discussion of the article and attention to this study.

BIBLIOGRAPHY

1. Veyl', I. G., "Hydrodynamic Schemes for Short-Range Forecasting," TRUDY GIDROMETTSENTRA SSSR (Transactions of the USSR Hydrometeorological Center), No 124, 1973.

2. Voloshchuk, V. M., "Vertical Turbulent Transfer in the Surface Layer," METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 10, 1975.

3. Voloshchuk, V. M., "Nonlocal Parameterization of Vertical Turbulent Exchange in the Surface Layer," METEOROLOGIYA I GIDROLOGIYA, No 6, 1976.

4. Koropalov, V. M. and Severov, D. A., "Propagation of a Light Pollutant Over Great Distances From a Linear Source," TRUDY IPG (Transactions of the Institute of Applied Geophysics), No 39, 1978.

5. Leys, Ye. K., "Two-Dimensional Turbulent Viscosity Coefficients," TRUDY 2-go TOKIYSKOGO SIMPOZIUMA PO CHISLENNYM METODAM PROGNOZA POGODY (Transactions of the Second Tokio Symposium on Numerical Methods of Weather Forecasting), Leningrad, Gidrometeoizdat, 1971.

6. METEOROLOGIYA I ATOMNAYA ENERGIYA (Meteorology and Atomic Energy), translated from English, edited by N. L. Byzova and K. P. Makhon'ko, Leningrad, Gidrometeoizdat, 1971.

7. Monin, A. S. and Yaglom, A. M., STATISTICHESKAYA GIDROMEKHANIKA (Statistical Hydromechanics), Moscow, Nauka, Part I, 1965, Part II, 1967.

8. Novikov, Ye. A., "Turbulent Diffusion in a Flow With a Transverse Velocity Gradient," PRIKLADNAYA MATEMATIKA I MEKHANIKA (Applied Mathematics and Mechanics), Vol 22, No 3, 1958.

9. Pinus, N. Z., "Energetics of Turbulent Movements in the Troposphere," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA (News of the USSR Academy of Sciences: Physics of the Atmosphere and Ocean), Vol 8, No 8, 1972.

10. Samarskiy, A. A., VVEDENIYE V TEORIYU RAZNOSTNYKH SKHEM (Introduction to Theory of Difference Schemes), Moscow, Nauka, 1971.

11. Aris, R., "On the Dispersion of a Solute in a Fluid Flowing Through a Tube," PROC. ROY. SOC. (London), A 235, 1956.

12. Corrsin, S., "Limitation of Gradient Transport Models in Random Walks and in Turbulence," TURBULENT DIFFUSION IN ENVIRONMENTAL POLLUTION, ADV. GEOPHYS., Vol 18A, 1974.

13. Crowford, T. V., "Atmospheric Diffusion of Large Clouds," PROC. OF THE USAEC METEOROL. INFORM. MEETING, 1967, CHALK RIVER, Canada, Rept. AECL-2787, 1968.

14. Csanady, G. T., "Diffusion in an Ekman Layer," J. ATMOS. SCI., Vol 26, No 3, 1969.

15. Csanady, G. T., TURBULENT DIFFUSION IN THE ENVIRONMENT, D., Reidal Publ. Co., 1973.

16. Knox, J. B., "Numerical Modeling of the Transport Diffusion and Deposition of Pollutants for Regions and Extended Scales," J. AIR POLLUT. CONT. ASSOC., Vol 24, No 7, 1974.

17. Pasquill, F., ATMOSPHERIC DIFFUSION, 2d Edition, John Wiley and Sons, New York, 1975.

18. Saffman, P. G., "The Effect of Wind Shear on Horizontal Spread From an Instantaneous Ground Source," QUART. J. ROY. METEOROL. SOC., Vol 88, No 378, 1962.

19. Syrakov, E., "On the Basic Dependence of the Relative Eddy Diffusion in Synoptic Scales for Rotating Atmosphere," Paper presented at the WMO Symposium on the Long-Range Transport of Pollutants and Its Relation to General Circulation Including Stratospheric/Tropospheric Exchange Processes, Sofia, 1-5 October 1979, WMO-No 538, Geneva, 1979.

20. Vinnichenko, N. K., "The Kinetic Energy Spectrum in the Free Atmosphere -- 1 Second to 5 Years," TELLUS, Vol 22, No 2, 1970.

UDC 551.524.72+551.547.5:519.3

METHOD FOR VARIATIONAL VERTICAL ADJUSTMENT OF CLIMATIC TEMPERATURE AND GEOPOTENTIAL FIELDS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 4 Jan 81) pp 26-33

[Article by K. G. Rubinshteyn, candidate of physical and mathematical sciences, and V. B. Shilyayev, All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center, and USSR Hydrometeorological Scientific Research Center]

[Abstract] A method is proposed for vertical adjustment of the temperature and geopotential fields as a solution of the variational problem. The authors have employed the traditional approximation of the equation of statics employed in the static monitoring of aerological data. Three possible variants of formulation of the variational problem are presented. Analytical solutions are given for two of these and the results of a numerical experiment are given for the third. The paper is presented in three parts: formulation of vertical adjustment problem in the form of a variational problem; adjustment algorithm; example of use of vertical adjustment method. The materials presented here indicate that use of the proposed method leads to retention of the fundamental structure of the climatic temperature and geopotential fields when there is assurance of precise satisfaction of the selected approximation of the equation of statics. At the present time work is proceeding on a more detailed analysis of the influence of adjustment on the initial fields, their integral characteristics and spectral properties. Future plans call for investigation of sensitivity of the adjustment method to changes in the weighting factors from the point of view of retaining the fundamental structure of the long-wave part of the field spectrum. After optimizing the method, it will be used in adjusting the archives of climatic aerological data created at the Moscow Division of the All-Union Scientific Research Institute of Hydrometeorological Information. Thus, the proposed method is a necessary part of the process of creating aerological archives. Figures 3; references 10: 6 Russian, 4 Western.

UDC 551.577.2(477.63)

PRECIPITATION DISTRIBUTION OVER TERRITORY OF EXPERIMENTAL METEOROLOGICAL POLYGON

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 3 Mar 81) pp 34-39

[Article by V. M. Muchnik, candidate of physical and mathematical sciences, Ukrainian Regional Scientific Research Institute]

[Text]

Abstract: Data are given on the distribution of summer prediction as a function of the direction of its transport.

In [1] we established statistically that stable local nonuniformities of precipitation exist (during the warm season of the year) over the territory of the Experimental Meteorological Polygon (EMP) of the Ukrainian Scientific Research Institute of the State Committee on Hydrometeorology and Environmental Monitoring. It was postulated that such a distribution of precipitation is attributable to the effect exerted by major industrial cities (especially Krivoy Rog, situated within the limits of the polygon) and large water bodies situated near the EMP. Accordingly, within the polygon there should be a dependence of the distribution of precipitation on the direction of its transport. In particular, it must be expected that with directions of transport from the west the distribution of precipitation over the territory will be determined by the influence of Krivoy Rog, especially since with the transport of precipitation with a westerly component the most abundant showers occur because the movement of fronts over the Ukraine in most cases occurs with westerly directions.

In order to clarify the influence of cities and water bodies on the distribution of precipitation over the territory of the EMP we compiled maps for the four principal directions of transport: northerly (315-045°), easterly (045-135°), southerly (135-225°) and westerly (225-315°). The directions of transfer of precipitation were determined from the prevailing direction of the wind in the layer 2-3 km [2] over the course of 24 hours. For this purpose we used the same data on precipitation for May-August 1966-1970 in the EMP which were used in [1].

Figure 1 shows that for all directions of transport of precipitation there is an extremely significant breakdown into local regions. As in [1], we will designate regions with an increased quantity of precipitation on the maps by the symbol "+" and regions with a decreased quantity by the symbol "-". As a convenience in comparison of maps of the distribution of precipitation for the different directions of transport with the general map published in [1] we reproduce it here as Fig. 2.

a) b)

c) d)

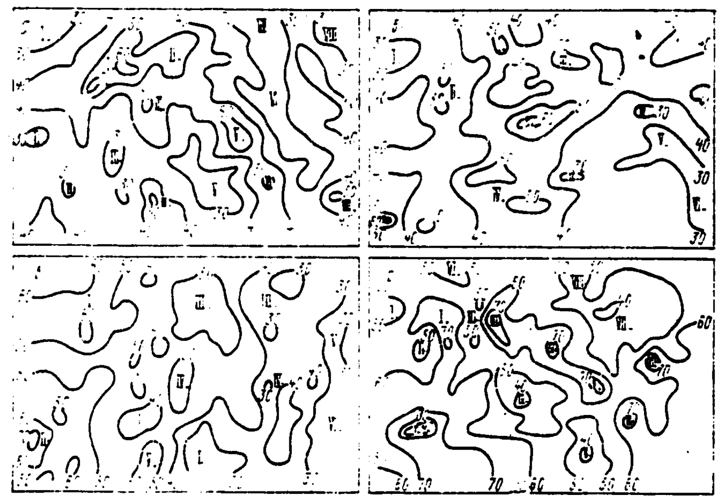

Fig. 1. Seasonal (May-August) precipitation maps for the Experimental Meteorological Polygon for 1966-1970 for directions of precipitation transport. a) northerly; b) easterly; c) southerly; d) westerly.

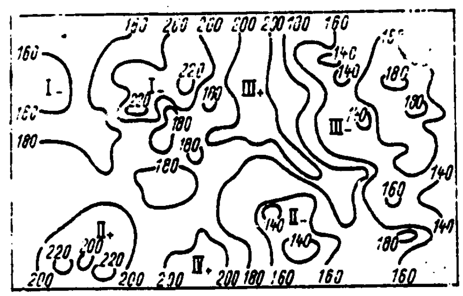

Fig. 2. Seasonal (May-August) precipitation map for the Experimental Meteorological Polygon for 1966-1970.

It follows from the precipitation distribution maps (Fig. 1) that with northerly (a), southerly (c) and westerly (d) directions of transport the maximum quantity of precipitation falls in the EMP. In the case of northerly and westerly directions the centers "+" are arranged for the most part from NW to SE. For example, on the map (a) the centers II^{n}_{+}, V^{n}_{+}, VI^{n}_{+} follow one another, whereas on map (d) -- the centers III^{w}_{+}, IV^{w}_{+}, V^{w}_{+}, VI^{w}_{+}. We note that the "-" centers exhibit approximately the same behavior. For example, on the map (a) the centers I^{n}_{-}, III^{n}_{-}, V^{n}_{-} are arranged in this direction.

Table 1

Coincidence of Centers "+" and "-" on Maps With Different Directions of the Transport of Precipitation During 1966-1970 With Regions "+" and "-" on the Overall Map for These Same Years

Direction of precipitation transport	I_+	II_+	III_+	VI_+	Σ_+		I_-	II_-	III_-	Σ_-	
					co	non-co				co	non-co
Northerly	+	x	+	+	3	0	x	+	+	2	0
Easterly	−+	+	−	+	4	1	+	+	+	3	0
Southerly	+	+	+	+	4	0	—	+	[illegible]	2	1
Westerly	+	+	+	—	3	1	+	+	+	3	0
					14	2				10	1

Note: co -- number of coincidences, nonco -- number of noncoincidences for all regions of precipitation.

Table 2

Frequency of Recurrence of Centers of Precipitation by Directions of Transport and Values of p Parameter for 1966-1970

Centers	Direction of precipitation transport				Σ
	northerly	easterly	southerly	westerly	
«–»	7	5	5	7	24
«—»	8	6	6	8	28
«+» И «—»	15	11	11	15	52
p	0.47	0.45	0.45	0.47	0.46
p_1	0.22	0.17	0.17	0.22	0.32
p_2	0.73	0.76	0.76	0.73	0,61

[И = and]

A further examination of the maps of distribution of precipitation by the directions of transport indicates that despite all the diversity there is one noteworthy feature: both the centers "+" and "-" are arranged on them in an extremely similar manner. This becomes especially obvious in a comparison of the arrangement of centers on the maps in Fig. 1 with the arrangement of regions of increased and reduced quantities of precipitation on the map in Fig. 2. These data are presented in Table 1. The coincidence of a center "+" with a region of increased quantity of precipitation and a center "-" with a region of reduced quantity of precipitation is noted in the table by the symbol "+" and their noncoincidence by the symbol "-".

We note that cases are possible when with a particular region of precipitation on the overall map there can at the same time be a coincidence with a center of one sign and a noncoincidence with a center of the other sign. In addition, there can be cases of absence of a coincidence, which are denoted by an "x".

Table 1 reveals that the number of coincidences of "+" and "-" centers with corresponding regions of precipitation on the overall map for 1966-1970 considerably exceeds the number of their coincidences for all directions of precipitation transfer.

These data indicate that not only with northerly and westerly directions of transport of precipitation onto the experimental polygon is there a manifestation of the influence of the peculiarities of the terrain on its distribution, but also with easterly and southerly directions. This influence evidently has a similar character for all directions. It can be assumed that with northerly and westerly directions of transport Krivoy Rog exerts an influence on the distribution of precipitation over the experimental meteorological polygon.

Table 3

Frequency of Recurrence of Centers of Precipitation by Directions of Transport for Individual Regions and Values of p Parameter for 1966-1970

Direction of precipitation transport	I+			II+			III+			IV+			Σ+			p
	c	H	o	c	H	o	c	H	o	c	H	o	c	H	o	
Northerly	7	1	0	2	5	0	6	5	0	2	2	2	17	13	2	0,57
Easterly	5	0	1	5	3	0	4	2	0	2	1	2	16	6	3	0,73
Southerly	4	1	0	4	3	0	4	3	1	2	1	2	14	8	3	0,64
Westerly	7	1	1	4	2	1	3	3	1	1	2	2	15	8	5	0,65
Σ	23	3	2	15	13	1	17	13	2	7	6	8	62	35	13	0,64
p		0,88			0,54			0,57			0,54			0,64		
p_1		0,68			0,34			0,38			0,25			0,54		
p_2		0,97			0,73			0,75			0,81			0,73		

c = co
H = nonco

Direction of precipitation transport	p_1	p_2	I−			II−			III−			Σ−			p	p_1	p_2
			c	H	o	c	H	o	c	H	o	c	H	o			
Northerly	0,38	0,75	5	0	0	4	2	1	11	3	0	20	5	1	0,20	0,08	0,41
Easterly	0,50	0,89	5	0	0	5	1	0	6	3	0	16	4	0	0,20	0,07	0,44
Southerly	0,41	0,83	4	1	0	5	1	0	11	3	0	20	5	0	0,20	0,08	0,41
Westerly	0,47	0,83	5	0	0	5	1	0	8	7	0	18	8	0	0,31	0,14	0,52
Σ	0,54	0,72	19	1	0	19	5	1	36	16	0	74	22	1	0,23	0,15	0,32
p				0,05			0,21			0,31			0,23				
p_1				0,01			0,08			0,18			0,15				
p_2				0,25			0,42			0,46			0,32				

Note: co -- number of coincidences, nonco -- number of noncoincidences, o -- cases of absence of coincidences or noncoincidences for individual regions of precipitation.

Now we will endeavor to ascertain whether the regions "+" and "-" on the maps of distribution of precipitation by directions of its transport is a random phenomenon or is governed by some constantly operative factors. For this we introduce some parameter p = m/n, where m is the number of the "+" centers and n is the total number of the "+" and "-" centers. For determining the limits $p-p_1$ and p_2 we will stipulate the 99% confidence level, as was done in [1]. The limits p_1 and p_2 will be determined from the p and n values using the nomogram in [3].

Table 4

Frequency of Recurrence of Centers of Precipitation by Directions of Transport and Values of the p Parameter From Annual Maps 1966-1970

Centers	Directions of precipitation transport				Σ
	northerly	easterly	southerly	westerly	
«+»	32	29	28	31	120
«—»	41	39	39	42	161
«+» и «—»	73	68	67	73	281
p	0,44	0,43	0,42	0,42	0,43
p_1	0,32	0,31	0,30	0,30	0,37
p_2	0,57	0,52	0,54	0,54	0,48

[И = and]

The data from the maps in Fig. 1 were used in determining the frequency of recurrence of "+" and "-" centers for different directions of precipitation transport. Table 2 indicates that the p values for different directions of transport of precipitation, although determined from a small number of cases, are approximately identical and on the average p = 0.46. This p value is already statistically more guaranteed. It was close to the mean value p = 0.41, determined using data on the distribution of precipitation by months for the same period of time [1].

In order to evaluate the hypothesis that the formation of "+" and "-" regions of precipitation in the experimental meteorological polygon is a result of some constant factors, we will undertake a comparison of the p parameters determined using the data in Table 1 with the corresponding p parameters according to the data in Table 2. Unfortunately, the data in these tables do not make it possible to carry out such a comparison separately for different directions of transport and individual regions of precipitation due to the low level of guaranteed probability. Accordingly, we will make such a comparison using total data for all directions and separately for all positive and negative regions of precipitation. From Table 1 $m^+ = 14$, $n^+ = 16$, $p^+ = 0.88$ and $m^{-1} = 1$, $n^- = 11$, $p^- = 0.09$. Using the nomogram from [3], employing these data we obtain $p_1^+ = 0.62$ and $p_2^+ = 0.98$, $p_1^- = 0.01$ and $p_2^- = 0.42$ respectively. From a comparison of p^+ and p^- with p it can be seen that these values differ greatly from one another and that their confidence limits p_1^+, p_2^+, p_1^-, p_2^- for all practical purposes lie outside the confidence limits p_1 and p_2 (Table 2). Thus, already on the basis of these data it is possible to assume to be confirmed the assumption that the distribution of precipitation over the experimental meteorological polygon by directions of transport is not a random event but is dependent on the influence of constantly operative factors.

Since it would be extremely desirable to establish the existence of the dependence of distribution of precipitation for individual directions of transport, we will undertake an examination of the frequency of recurrence of the "+" and "-" centers using the data cited in Table 3.

As indicated by Table 3, the p value for all positive regions of precipitation for all directions of transport considerably differs from the p value for negative regions: $p(\sum_+) = 0.64$ and $p(\sum_-) = 0.23$ respectively. At the same time, the

$p_1(\Sigma_+) = 0.54$ value for positive regions does not overlap the value $p_2(\Sigma_-) = 0.32$ for negative regions. This indicates unambiguously that the distribution of precipitation for positive regions differs completely from the distribution for negative regions.

We will make the same comparison for values of the p parameter for individual positive regions of precipitation with p values for all the negative regions. It appears that the values $p(I_+) = 0.88$, $p(II_+) = 0.54$, $p(III_+) = 0.57$ and $p(IV_+) = 0.54$ considerably differ from $p(\Sigma_-) = 0.23$, and $p_1(I_+) = 0.38$ and $p_1(III_+) = 0.38$ do not overlap with $p_2(\Sigma_-) = 0.32$. Only $p_1(IV_+) = 0.25$ to some degree overlaps with $p_2(\Sigma_-)$. It can therefore be assumed that the distribution of precipitation in the regions I_+, II_+, III_+, and in all probability, IV_+ differs from the distribution in the negative regions of precipitation.

Now we will compare the values of the p parameter for individual negative regions of precipitation with the p value for all the positive regions. It is found that $p(I_-) = 0.05$, $p(II_-) = 0.21$ and $p(III_-) = 0.31$ differ greatly from $p(\Sigma_+) = 0.64$, and the values $p_2(I_-) = 0.25$, $p_2(II_-) = 0.42$ and $p_2(III_-) = 0.46$ fall below the values $p_1(\Sigma_+) = 0.54$. Thus, we obtained still a further proof that the distribution of precipitation in positive and negative regions belongs to different sets.

Now we will make a similar analysis of data for positive and negative regions separately for each direction of precipitation transport. Table 3 shows that virtually all the values of the parameters $p_1(\Sigma_+)$ fall below or extremely insignificantly overlap the values $p_2(\Sigma_-)$. It can therefore be asserted that the distributions of precipitation in positive and negative regions for all directions of transport of precipitation belong to different sets.

Now we will attempt to clarify to what extent there is justification of the hypothesis that the distributions of precipitation for positive and negative regions for individual directions of transport are not a result of random events but are caused by some constantly operative factors. For this we will compare the values of the parameter p (Table 3) with the values obtained from annual seasonal maps (Table 4). These latter values are the most reliable since they were obtained on the basis of a large number of cases.

It follows from this comparison that the $p(\Sigma_+)$ and $p(\Sigma_-)$ values for all directions of precipitation transport are considerably greater than and less than the $p(\Sigma)$ values respectively. But at the same time, only for easterly and westerly directions of precipitation transport does the entire range of $p_1(\Sigma_+)$-$p_2(\Sigma_+)$ values fall outside the range of $p_1(\Sigma)$-$p_2(\Sigma)$ values. For northerly and southerly directions of transport there is an appreciable overlapping of these ranges. A completely different situation is observed for negative regions of precipitation. For example, for northerly and southerly directions of transport of precipitation the range of $p_1(\Sigma_-)$-$p_2(\Sigma_-)$ values falls virtually outside the range of $p_1(\Sigma)$-$p_2(\Sigma)$ values, whereas for easterly and westerly directions these ranges almost completely overlap.

From the comparison of the values of the p parameter on the basis of Tables 3 and 4 it follows that we have confirmation of the hypothesis that the distribution of precipitation over the territory of the experimental meteorological polygon is not a result of random events but is caused by constantly operative factors and with any direction of transport. However, the existing area of the network in the experimental polygon is inadequate for determining all the local reasons for modification of the distribution of precipitation.

We point out in conclusion that an increase in the duration of the series of used precipitation observations in the experimental meteorological polygon (which is now completely feasible) will make it possible to obtain more valid data for solution of the problems considered in this study. In addition, it can be assumed that the implementation of this type of research for the winter period of the year will make it possible to obtain an answer to certain questions. In particular, from a comparison of the distributions of precipitation during summer and winter it is possible to some degree to clarify whether the water bodies around the experimental meteorological polygon exert an appreciable influence on the distribution of precipitation since in winter such an influence must be virtually absent. We note that an investigation of the distribution of precipitation during the cold season of the year in the experimental meteorological polygon is of independent importance, especially for studies in the field of artificial modification and agrometeorology carried out in this territory.

BIBLIOGRAPHY

1. Muchnik, V. M., "Statistical Indices of Distribution of Precipitation in the Experimental Meteorological Polygon," METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 12, 1978.

2. Stepenenko, V. D., RADIOLOKATSIYA V METEOROLOGII (Radar and Meteorology), Leningrad, Gidrometeoizdat, 1973.

3. Khan, G. and Shapiro, S., STATISTICHESKIYE MODELI V INZHENERNYKH ZADACHAKH (Statistical Models in Engineering Problems), Moscow, Mir, 1969.

UDC 551.521.3

OPTICAL PROPERTIES OF CLOUDS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 17 Feb 81) pp 40-43

[Article by V. V. Kuznetsov and L. N. Pavlova, candidate of physical and mathematical sciences, Institute of Experimental Meteorology]

[Text]

Abstract: The dependence of values of the linear depolarization ratio in a backscattered signal D_π on the contribution of droplets p_{drop} to the volumetric scattering coefficient for a mixed cloud is examined. The authors propose a semiempirical expression for determining p_{drop} for known D_π. The article gives measurements and computations of the scattering indicatrices for media with a mixed phase content characterized by different D_π values.

It is known that clouds with a mixed phase composition can consist in their entire thickness of a mixture of supercooled droplets and crystals or of successive layers of droplets, crystals or their mixture. Clouds which are mixed in their entire thickness are encountered most frequently.

The optical properties of mixed clouds should be determined by the optical characteristics of both liquid and solid particles which are present in the clouds. Researchers do not always have data on the relative concentration and spectra of sizes of droplets and crystals in a mixed cloud. However, the relative contribution of the droplets and crystals exerts a definite influence on the values of the linear depolarization ratio D_π in the backscattered signal [4-6], which can be determined by remote sounding of a cloud, as a result of which it is convenient to use this parameter as a characteristic of mixed clouds.

We will examine the influence of the liquid phase in a cloud with a mixed phase composition on the values of the volumetric scattering coefficient, scattering indicatrix and D_π.

We will introduce the following notations: $i_{drop}(\theta)$, $i_{cr}(\theta)$ and $i_{mix}(\theta)$ -- normalized values of the scattering indicatrix for droplets, crystalline particles and their mixtures respectively; $\sigma_{drop}(\lambda)$, $\sigma_{cr}(\lambda)$ and $\sigma_{mix}(\lambda)$ are the volumetric coefficients of scattering of droplets, crystals and their mixtures;

$p_{drop}(\lambda) = \sigma_{drop}(\lambda)/\sigma_{mix}(\lambda)$ is the contribution of droplets to the volumetric scattering coefficient of a mixed cloud.

With the propagation of plane-polarized radiation through a mixed medium the polarized components in the backscattered signal can be written in the following way:

[k = drop(let);
kp - cr(ystal);
cm = mix(ed).]

$$I_{\perp}(\pi) \sim \sigma_{cm}(\lambda)[i_{k\perp}(\pi) p_k(\lambda) + i_{kp\perp}(\pi)[1 - p_k(\lambda)]] e^{-\alpha(\lambda) L};$$
$$I_{\parallel}(\pi) \sim \sigma_{cm}(\lambda) i_{k\parallel}(\pi) p_k(\lambda) + i_{kp\parallel}(\pi)[1 - p_k(\lambda)]] e^{-\alpha(\lambda) L}, \quad (1)$$

where $I_{\perp}(\pi)$ and $I_{\parallel}(\pi)$ are the components of backscattered radiation with a polarization perpendicular and parallel to the polarization of the incident radiation; $\alpha(\lambda)$ is the index of attenuation of the medium; L is the backscattering measurement path.

It is known that with the backscattering of polarized radiation by spherical particles a state of polarization of the incident radiation is maintained [6]. Therefore, the contribution of droplets $i_{drop\perp}(\pi)\, p_{drop}(\lambda)$ to the signal $I_{\perp}(\pi)$ can be neglected.

The linear depolarization ratio D_{π} for a mixed medium is determined as follows:

$$D_{\pi} \approx \frac{I_{\perp}(\pi)}{I_{\parallel}(\pi)} \approx D_{\pi}^{*} \frac{1 - p_k(\lambda)}{1 + p_k(\lambda)(B_{\pi} - 1)}, \quad (2)$$

where $D_{\pi}^{*} = i_{cr\perp}(\pi)/i_{cr\parallel}(\pi)$ is the depolarization ratio for radiation with the wavelength λ in a crystalline medium:

$$B_{\pi} = i_{drop\parallel}(\pi)/i_{cr\parallel}(\pi).$$

It follows from (2) that by knowing D_{π}^{*} and B_{π} it is possible to determine the contribution of droplets to the volumetric scattering coefficient of the mixture for each D_{π} [5]:

[k = drop(let)]

$$p_k(\lambda) \approx \frac{D_{\pi}^{*} - D_{\pi}}{D_{\pi}(B_{\pi} - 1) + D_{\pi}^{*}} \quad \text{when } D_{\pi} \leqslant D_{\pi}^{*}. \quad (3)$$

And knowing the $p_{drop}(\lambda)$ values and the optical characteristics of the droplets and crystals, it is also possible to determine other optical characteristics of a mixed cloud, such as the scattering indicatrix:

[cm = mix(ed);
kp = cr(ystal);
k = drop(let)]

$$i_{cm}(\theta) = i_k(\theta) p_k(\lambda) + i_{kp}(\theta)[1 - p_k(\lambda)]. \quad (4)$$

Thus, it is of interest to measure the D_{π}^{*} and B_{π} values for crystalline media with a different microstructure, since it is impossible to compute these parameters.

For radiation with $\lambda = 0.63\mu m$ the D_{π}^{*} and B_{π} values were measured in cold chambers in [4, 7, 9]. On the basis of the results in [7] it can be assumed that $D_{\pi}^{*} = 0.5$ for crystals of different size and shape.

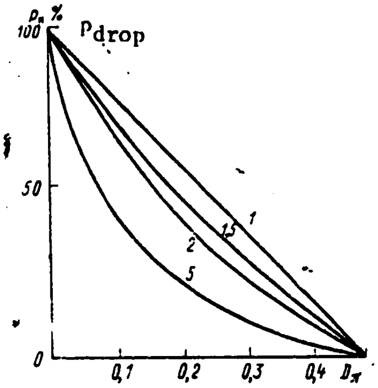

Fig. 1. Dependence of p_{drop} on D_π for different B_π values (B_π are indicated by the figures on the curves).

At the present time there is no complete clarity concerning the B_π values. In investigations in [4] for crystals of different shape measuring 10-200μm it was possible to obtain a value $B_\pi = 1.5(\pm 30\%)$, which in [8] was confirmed by measurements of light scattering by hydrometeors. However, in [9] for ice crystals measuring less than 20μm the value $i_{cr\parallel}(\pi) = 0.0101$ was obtained. This was substantially lower than $i_{drop\parallel}(\pi)$ for models of a droplet cloud [2] (thus, for model S.1 $i_{drop}(\pi) = 0.05\ 055$). With these normalized values the scattering index for crystals and droplets is $B_\pi = 5$. It should be noted that the latest data [9] were obtained by the extrapolation of values measured with $\theta = 175°$.

The discrepancy in the results of determination of B_π in [4, 8] and [9] can be attributed to the influence of the size of the crystals on the $i_{cr\parallel}(\pi)$ values or a measurement error which has not been taken into account. Figure 1 shows how sensitive the $p_{drop}(\lambda)$ values are to a change in D_π with different B_π.

In order to determine the B_π value in a cold chamber with a volume of 100 m^3 we carried out a series of measurements. The measurement method involved the following. Plane-polarized radiation with $\lambda = 0.63\mu$m was directed along a horizontal path into a chamber where droplet and crystalline fogs were created. A detector received the radiation scattered at angles $\theta = 178°40'$ ($\pm 30'$) in the horizontal scattering plane. At the same time we made measurements of the optical thickness of the medium $\tau_{0.63}$. The B_π value was determined as the ratio of the parallely polarized components of the intensity of radiation scattered in droplet and crystalline fogs with identical $\tau_{0.63}$ values. The measurements were made with vertical and horizontal polarizations of the incident radiation. In the case of vertical polarization of the incident radiation (the $\bar{E}$ vector oscillates in the vertical plane) the averaged B_π values for crystals of platy and acicular forms are different: for prisms measuring from 10 x 10 to 40 x 150μm $B_\pi = 1.5(\pm 22\%)$ (a total of 96 measurements), whereas for platelets (and "stars") $B_\pi = 2.2(\pm 40\%)$ (164 measurements). In individual experiments for platelets the measured B_π values attained 3.4. In the case of horizontal polarization for platelets and prisms $B_\pi = 1.3(\pm 30\%)$ (67 measurements).

Thus, the measurements indicated that the B_π value is dependent on the relative orientation of the polarization plane for incident radiation and the plane of scattering measurement. With their orthogonality the B_π value is sensitive to the form of crystals.

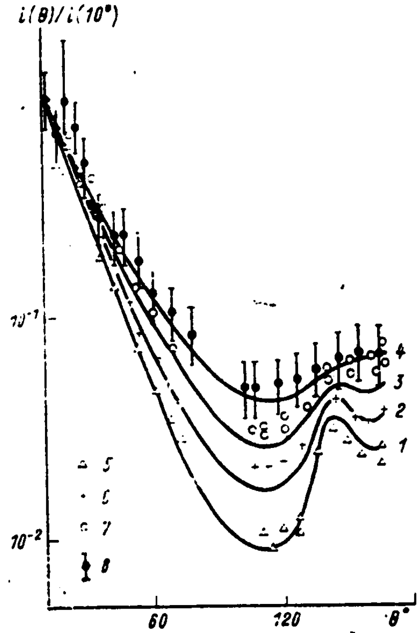

Fig. 2. Comparison of computed values of indicatrix of mixed cloud (curves 1-4) with experimental indicatrices (5-8); 5) D_π = 0.08-0.15; 6) D_π = 0.22-0.27; 7) D_π = 0.30-0.34; 8) $D_\pi > 0.35$.

Figure 2 shows the results of computations and measurements of the relative scattering indicatrix for a mixed cloud with different D_π values. The computations were made for D_π = 0.1(0.1)0.4. In the computations use was made of the $i_{drop}(\theta)$ values with $\lambda = 0.7 \mu$ m for the S.1 value [2] and as $i_{cr}(\theta)$ -- the experimental data in [1] (without allowance for the halo), B_π = 1.5 and $D_\pi^* = 0.5$. As indicated by the computed curves, $i_{mix}(\theta)/i_{mix}(10°)$ with an increase reveals the greatest change in the region of lateral scattering angles. In addition, there is a smoothing of the maximum in the corners of the rainbow. In the experiments a mixed medium was created in the chamber by the introduction of AgI crystallization nuclei into a supercooled droplet fog. As crystallization continued measurements were made of the D_π values (with $\theta \approx 179°$ and vertical polarization of the incident radiation) and the indicatrices in the horizontal scattering plane. The time required for measuring the indicatrix in the range of scattering angles θ = 10-170° was 10 sec [3]. The relative error in measurements of $i_{mix}(\theta)$ and D_π did not exceed ±10%. The experimental results agree well with the computed values, thereby confirming the recults of measurement of the B_π parameter.

Thus, it was shown that the D_π parameter can be used as a basis for the classification of mixed clouds on the basis of the contribution of the droplet fraction $p_{drop}(\lambda)$ to the volumetric scattering coefficient and, knowing D_π it is possible to determine the optical characteristics of mixed clouds. It should be noted that this requires the making of measurements of B_{π} in natural crystalline and droplet clouds for specific optical systems of lidars and for different observation angles.

The authors express sincere appreciation to O. A. Volkovitskiy for attention to the work.

BIBLIOGRAPHY

1. Volkovitskiy, O. A., Pavlova, L. N. and Petrushin, A. G., "Optical Properties of Crystalline Clouds," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA (News of the USSR Academy of Sciences: Physics of the Atmosphere and Ocean), Vol 16, No 2, 1980.

2. Deyrmendzhan, D., RASSEYANIYE ELEKTROMAGNITNOGO IZLUCHENIYA SFERICHESKIMI POLIDISPERSNYMI CHASTITSAMI (Electromagnetic Radiation Scattering by Spherical Polydisperse Particles), translated from English, Moscow, Mir, 1971.

3. Nikiforova, N. K., Pavlova, L. N. and Snykov, V. P., "'Rassvet' Velocity Instrument for Measuring the Scattering Indicatrix," TRUDY IEM (Transactions of the Institute of Experimental Meteorology), No 4(38), 1978.

4. Pavlova, L. N., "Investigation of the Attenuation and Scattering of Laser Radiation in a Medium Containing Ice Crystals," Author's Summary of Dissertation for Award of the Academic Degree of Candidate of Physical and Mathematical Sciences, Obninsk, IEM, 1978.

5. Pavlova, L. N., "Method for Polarimetric Analysis of the Optical Properties of Suspended Particles," Author's Certificate USSR No 731363, BYULLETEN' IZOBRET. (Inventors' Bulletin), No 16, 1980.

6. Khyulst, G., RASSEYANIYE SVETA MALYMI CHASTITSAMI (Light Scattering by Small Particles), Moscow, IL, 1961.

7. Sassen, K., "Depolarization of Laser Light Backscattered by Artificial Clouds," J. APPL. METEOROL., Vol 13, No 8, 1974.

8. Sassen, K., "Backscattering Cross Sections for Hydrometeors: Measurements at 6328 A," APPL. OPTICS., Vol 17, No 5, 1978.

9. Sassen, K. and Liou, K. N., "Scattering of Polarized Laser Light by Water Droplets, Mixed Phase and Ice Crystal Clouds. Part I. Angular Scattering Patterns," J. ATMOS. SCI., Vol 36, No 5, 1979.

UDC 551.521.32

METHOD FOR COMPUTING EFFECTIVE RADIATION OF THE OCEAN SURFACE WITH ALLOWANCE FOR DIFFERENT CLOUD LEVELS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 4 Feb 81) pp 44-52

[Article by G. V. Girdyuk, candidate of geographical sciences, and S. P. Malevskiy-Malevich, candidate of physical and mathematical sciences, Murmansk Affiliate, Arctic and Antarctic Institute, and Main Geophysical Observatory]

[Text]

Abstract: The article gives the results of checking of a method for computing long-wave atmospheric radiation over the ocean, proposed by the authors earlier, using measurements of this parameter made on a number of voyages of scientific research vessels. The results of measurements made it possible to refine this method due to separate allowance for the influence of clouds at different levels. The corresponding coefficients for different air temperature values are given. A method is proposed for correcting the dependences for their use in climatological computations.

In [3] we proposed a method for computing long-wave atmospheric radiation and effective radiation of the ocean surface. This method, in tabulated form, is given in a recent edition of the OCEANOGRAPHIC TABLES [13]. Its individual points have been checked in a number of subsequent studies [4-9, 12].

According to [3], the atmospheric radiation E_a over the ocean is determined on the basis of data on the temperature of the near-water air layer and the tenths of total cloud cover. The characteristics of air humidity in explicit form are not taken into account as a result of the high correlation of temperature and absolute air humidity values over the ocean [3, 5, 11].

With conversion to standard units the expression derived in [3] for computing long-wave atmospheric radiation E_a in KW/m^2 has the form

$$E_a = (1,026\, T_a^2 \cdot 10^{-5} - 0,541)(1 + k_0 n_0^2), \tag{1}$$

Table 1

Data on Measurements of Atmospheric Radiation in Different Regions of World Ocean

Year	Vessel	Measurement Region	$\bar{n}_0$	σ_n	$\bar{t}_a$	σ_t	Number of measurements
1965	"Aysberg"	North Atlantic, Norwegian Sea	7.4	2.8	14.9	3.3	663
1966	"Polyarnik"	Barents Sea	8.2	2.5	7.1	1.6	65
1967	"Voskhod"	Barents Sea	7.0	3.0	-6.4	4.0	51
	"Sevastopol'"	Northwestern Atlantic	7.6	2.8	5.3	5.5	274
	"Okeanograf"	North Atlantic	3.0	3.0	18.7	0.7	69
1969	"Okeanograf"	North Atlantic	5.4	3.2	19.6	2.1	147
1972	"Passat"	Equatorial Atlantic	7.5	2.8	25.7	1.0	406
1973	"Akademik Shirshov"	Northern and equatorial part of Pacific Ocean, southern and equatorial parts of Indian Ocean	5.2	3.2	23.4	5.8	450
1974	"E. Krenkel'"	Equatorial Atlantic	7.4	2.8	26.1	0.6	452
	"Polyarnik"	Barents Sea	8.7	2.2	3.0	2.4	185
	"Voskhod"	Barents Sea	7.9	2.6	-1.2	3.1	272
1975	"Aysberg"	Barents Sea	8.0	2.6	-3.9	3.6	441
	"Aysberg"	Barents Sea	8.6	2.2	0.7	2.7	187
	"Vs. Berezkin"	Sea of Japan, East China Sea and South China Sea, equatorial part of Indian Ocean	5.9	3.2	28.2	1.8	240
1976	"Vs. Berezkin"	Barents and Norwegian Seas	7.7	2.8	5.2	4.9	446
1977	"Vs. Berezkin"	Barents and Norwegian Seas	7.6	2.8	0.2	-.2	376
	"Vs. Berezkin"	Barents, Norwegian and Greenland Seas	8.6	2.2	3.0	3.8	420
	"Vs. Berezkin"	Barents, Norwegian and Greenland Seas	8.3	2.4	0.2	3.4	136
1978	"Vs. Berezkin"	North Atlantic, Barents and Norwegian Seas	8.2	2.5	2.0	3.1	421
1979	"O. Shmidt"	Greenland, Norwegian and Barents Seas	8.8	2.1	-1.2	4.5	373

where T_a is air temperature in °K; n_0 is the tenths of total cloud cover.

The first factor in expression (1) represents atmospheric radiation in a cloudless sky $E_{a,0}$. As demonstrated in [3, 4], the values of the coefficients k_0, taking into account the influence of total cloud cover on atmospheric radiation, are dependent on air temperature. They were determined on the basis of experimental data from the expression

$$k_{0(t)} = \frac{E_{a,10(t)} - E_{a,0(t)}}{E_{a,0(t)}}, \tag{2}$$

where $E_{a,10(t)}$ is atmospheric radiation at the time of continuous cloud cover and the determined air temperature values. $E_{a,0(t)}$ is the same for a cloudless sky and the same temperature values.

The analysis indicated that with 10/10 cloud cover the atmospheric radiation value can be approximated by the following dependence (in KW/m^2):

$$E_{a,10} = 0{,}928\, T_a^2 \cdot 10^{-5} - 0{,}397. \tag{3}$$

Dependence (1) and the numerical values k_0 were obtained using data from approximately 1100 measurements of atmospheric radiation made using a Main Geophysical Observatory radiometer with a germanium filter [1, 10] in 1965-1969 in the North Atlantic, Norwegian and Barents Seas [3]. During subsequent years observations with the Main Geophysical Observatory radiometer and an unchanged measurement method and the same procedures for checking the instruments were made on a number of voyages of the scientific-research ships. During the period 1965-1979 the total number of measurements exceeded 6000. The observations covered a considerable part of the area of the world ocean: they were made in the northern and equatorial parts of the Atlantic and Pacific Oceans, in the equatorial and southern parts of the Indian Ocean and in the seas of the northern Arctic Ocean basin. Table 1 gives the mean values of total cloud cover and air temperature for each voyage and the dispersions of these parameters. An analysis of this material made it possible to check the method in [3] and its refinement by taking into account the influence of different cloud cover levels on the formation of atmospheric radiation, especially important in computations of the unaveraged radiation flux values.

The checking of the method in [3] by means of a comparison of the results of computations with data from individual measurements was carried out on some of these voyages [6, 7, 9, 12]. Table 2 gives a comparison of the measured ($E_{a,meas}$) and computed ($E_{a,comp}$) atmospheric radiation values for the entire mass of data with averaging of these results within individual groups, discriminated on the basis of the gradations of the determining parameters (air temperature and cloud cover tenths).

The data in Table 2 reveal the absence of significant discrepancies in the results of measurements and computations for the entire possible range of initial data. The maximum discrepancy for individual gradations of air temperature and cloud cover is ±(0.6-1.2%).

If we regard the cited values of the discrepancies as the errors in the computation method, in computations of effective radiation of the ocean surface

Table 2

Comparison of Results of Measurements and Computations of Atmospheric Radiation, KW/m^2

n_o	$\overline{E}_{a.}$ meas	$\overline{t}_a$	$\overline{n_o^2}$	$\overline{E}_{a.}$ comp	%	Number of cases	t_a	$\overline{F}_{a.}$ meas	$\overline{t}_a$	$\overline{n_o^2}$	$\overline{E}_{a.}$ comp	%	Number of cases
	Grouping by cloud cover							Grouping by air temperature					
0	0.297	12.6	0,000	0,296	—0,3	276	-15 — —5	0.239	—7.6	0.730	0.236	—1.2	403
1—2	0,306	13.7	0.026	0.304	—0,6	363	—5—5	0,279	0.3	0,755	0.279	0.0	2444
3—7	0.319	13.2	0.285	0.317	—0,6	1526	5—15	0.323	9.6	0.704	0.325	+0.6	1222
8—9	0.329	10.4	0,721	0.330	+0,3	1041	15—25	0.367	19.4	0,556	0.370	+0,8	627
10	0.326	6.1	1.000	0,326	0,0	2811	25—35	0.406	26.3	0.498	0.406	0.0	1321
Entire mass	0.322	9.4	0.666	0,322	0,0	6017							

$$E_{eff} = \varepsilon (\sigma T_0^4 - E_a), \tag{4}$$

where ε is the integral emissivity of the water surface, $\varepsilon = 0.91$ [2], σ is the Stefan-Boltzmann constant, $\sigma = 0.567 \cdot 10^{-10}$ KW/(m$^2 \cdot$K^4); T_0 is water surface temperature in °K, they do not exceed 10% (with $E_{eff} > 0.035$ KW/m^2).

Thus, the checking of the method on the basis of adequately extensive experimental data revealed its universality and the possibility of use in the form proposed in [3]. At the same time, as a result of the "averaged" allowance for the influence of cloud cover on the formation of atmospheric radiation (use of data only on total cloud cover with corresponding temperature coefficients), the errors in this method can be substantial in computations for individual moments in time, especially in the case of a predominance of upper-level clouds [12].

The available mass of measurement data, a list of which is given in Table 1, made it possible to refine the role of clouds at different levels in the general flux of long-wave atmospheric radiation (some preliminary data with the use of some of these materials are given in [9]).

The sampling of measurement data and their processing led to the following type of computation expressions for the conditions of a cloud cover of 10/10 (in KW/m^2):

-- for upper-level cloud cover

$$E_{a.10} = 0{,}995\, T_a^2 \cdot 10^{-5} - 0{,}496; \tag{5}$$

-- for middle-level cloud cover

$$E_{a.10} = 0{,}932\, T_a^2 \cdot 10^{-5} - 0{,}401; \tag{6}$$

-- for lower-level cloud cover

$$E_{a.10} = 0{,}921\, T_a^2 \cdot 10^{-5} - 0{,}385. \tag{7}$$

Figure 1 gives the atmospheric radiation values for a cloudless sky and with continuous cloud cover at different levels computed using the expressions cited here, normalized for the radiation of an ideally black body at air temperature -- atmospheric emissivity $E_a/\sigma T_a^4$. It follows from this figure that the degree of influence of clouds at different levels on atmospheric radiation decreases with an increase in air temperature. For example, with t_a = -20°C the emissivity of the atmosphere varies from 0.50 to 0.88 with transition from some extreme conditions (cloudless sky) to others (continuous cloud cover at the lower level). With t_a = 30°C this value varies from 0.84 to 0.96 respectively. Accordingly, detailed allowance for the level structure of clouds in computations of atmospheric radiation over the ocean is extremely important for the polar and temperate latitudes and is less important for the tropical and equatorial latitudes.

It also follows from Fig. 1 that the atmospheric emissivity values in the presence of a middle-level cloud cover and with a total cloud cover virtually coincide. This means that the influence of middle-level clouds on the formation of atmospheric radiation over the ocean reflects some "mean" conditions for the receipt of long-wave radiation in the presence of a cloudy sky, taking into account the real distribution of the frequency of recurrence of clouds at different levels. At the same time, with a middle-level cloud cover the $E_a/\sigma T_a^4$ value is closer to the conditions of lower-level cloud cover than to upper-level conditions. However, cloud cover observations do not provide for a separate determination of the quantity of clouds at the middle and upper levels. Therefore, in computations of atmospheric radiation it is impossible to take into account the influence of middle- and upper-level clouds separately, except for those cases when there is cloud cover at only one of these levels.

Accordingly, the influence of the different levels of clouds on atmospheric radiation in a general case can be determined only by the separation of total cloud cover into clouds of the lower and middle + upper levels.

Then

[H = low; C = mid; B = up]

$$E_a = E_{a.o}(1 + k_н n_н^2)[1 + k_{с+в}(n_о^2 - n_н^2)], \tag{8}$$

where n_{low} is the tenths of lower cloud cover; k_{low}, k_{mid+up} are coefficients for taking into account the influence of clouds at the lower and middle + upper levels.

It is assumed here that the lower-level cloud cover completely screens the thermal influence of clouds at higher levels. For determining the coefficients k_{mid+up} necessary for computations using formula (8), we have the dependence

$$E_{a.10} = 0{,}964\, T_a^2 \cdot 10^{-5} - 0{,}448 \tag{9}$$

on the assumption of an equal probability of clouds of the middle and upper levels over the world ocean. This assumption must be introduced in connection with the fact that real data on the frequency of recurrence of clouds at these levels are available only for the areas of some seas.

The computed values of the k coefficients for all three cloud levels, for total cloud cover and cloud cover of the middle+upper levels are given in Table 3.

The k_{mid+up} values were computed using formula (2), taking into account expressions (9). They can also be determined from (7) and (8) as

[c = mid; B = up; H = low]

$$k_{с+в} = \frac{k_о n_о^2 - k_н n_н^2}{(1 + k_о n_о^2)(n_о^2 + n_н^2)}. \tag{10}$$

Our computations of the k_{mid+up} values using formula (10), with the mean k_0 and k_{low} values taken into account, using data on cloud cover [15], made it possible to check the reliability of the k_{mid+up} values cited in Table 3. In general, for the world ocean (the mean t_a value according to all these data was 17°C) the use of formula (10) led to a k_{mid+up} value equal to 0.13, which agrees well with the data in Table 3.

Thus, for determining atmospheric radiation in the presence of a cloud cover of one of these levels it is possible to use formula (1) with corresponding n_{low}, n_{mid} or n_{up} values and the coefficients n_{low}, n_{mid} or n_{up} cited in Table 3. In all other cases the computations must be made using expression (8) and the values of the coefficients k_{low} and k_{mid+up} given in Table 3.

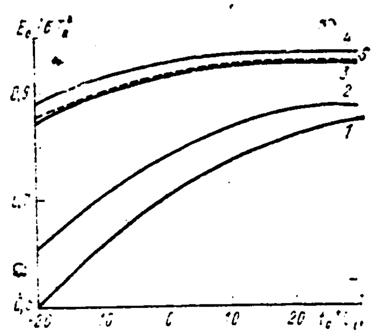

Fig. 1. Dependence of ratio $E_a/\sigma T_a^4$ on air temperature for different cloud cover conditions. 1) cloudless sky, 2) cloud cover 10/10 at upper level, 3) cloud cover 10/10 at middle level, 4) cloud cover 10/10 at lower level, 5) total cloud cover 10/10.

We note once again that the use of formula (8) improves the results of computations in these cases when there is a predominance of lower or middle+upper cloud cover, and with adequate averaging the use of formulas (1) and (8) leads virtually to the same results if the frequency of recurrence of clouds by levels does not have systematic deviations from some mean conditions.

With the use of expressions (1) and (8) for determining the averaged $\bar{E}_a$ values it is necessary to use data on the mean squares of the input parameters $\overline{n^2}$ and $\overline{T_a^2}$, but using reference data it is possible to obtain information on the square of the mean values. This makes it necessary to correct the computational expressions for their use in computing the mean values of the long-wave radiation fluxes.

An analysis of the errors arising because of this indicated that the differences between $\overline{T_a^2}$ and T_0^2 do not have any significant influence on the results of computations: they can change the radiation flux by 0.01 KW/m^2 only with σ_t values exceeding 10°C. However, the characteristic σ values for air temperature are 2-4°C (Table 1).

In order to take into account the differences between $\overline{n_0^2}$ and $\bar{n}_0^2$ in [4] it is proposed that a correction factor be introduced

$$\beta = \frac{1 + k_0 \overline{n_0^2}}{1 + k_0 \bar{n}_0^2}. \qquad (11)$$

In turn, the differences between $\overline{n_0^2}$ and $\bar{n}_0^2$ are determined by the known expression

$$\overline{n_0^2} = \bar{n}_0^2 + \sigma_n^2. \qquad (12)$$

For computing the standard deviation for the tenths of total cloud cover σ_n we used cloud cover observations made four times a day on nine weather ships in the North Atlantic during 1956-1968. The results of the computations were grouped by gradations of the mean monthly tenths of total cloud cover. Table 4 gives the σ_n values combined for all weather ships corresponding to a definite total cloud cover unit. It also gives the σ_{σ_n} values. The data in Table 4 make it possible to express the correlation between the mean tenth of total cloud cover and the dispersions of this value in the form

$$\sigma_n^2 = 0.42\,\bar{n}_0\,(1 - \bar{n}_0), \tag{13}$$

where σ_n, the same as n_0, in contrast to the data in Table 4, are expressed in fractions of unity. Observational data show that the dependence of (13) is real not only for total cloud cover, but also for lower-level cloud cover.

Table 3

Values of Coefficients for Total (k_0), Lower (k_{low}), Middle (k_{mid}), Upper (k_{up}) and Middle+Upper (k_{mid+up}) Cloud Cover for Different Air Temperatures

	t_a °C					
	−20	−10	0	10	20	30
k_0	0.70	0.45	0.32	0.23	0.18	0.13
k_{low}	0.76	0.49	0.35	0.26	0.20	0.15
k_{mid}	0.68	0.44	0.31	0.23	0.18	0.13
k_{up}	0.22	0.14	0.10	0.07	0.06	0.04
k_{mid+up}	0.46	0.30	0.21	0.15	0.12	0.09

Table 4

Mean σ_n and σ_{σ_n} Values for Total Cloud Cover in North Atlantic

	$\bar{n}_0$							
	5,97	6,52	7,04	7,51	8,00	8,46	8,98	9,41
σ_n	3,23	3,13	2,96	2,78	2,54	2,25	1,83	1,50
σ_{σ_n}	0,21	0,26	0,26	0,25	0,24	0,24	0,25	0,20
Number of months	10	42	112	269	284	215	97	8

For checking (13) we used data on the frequency of recurrence of the total cloud cover unit in 10° zones of the world ocean obtained by L. A. Strokina on the basis of materials from the sea climatic atlas [15]. The frequency of recurrence of the total cloud cover unit for the latitude zones of the world ocean was determined at 248 points for the four central months of the seasons. For computing $\bar{n}_0^2$ and $\bar{n}_0^2$ we used the mean annual values of the cloud cover unit. As a whole for the world ocean (70°N–65°S) it was found that $\bar{n}_0^2 = 0.64$, $\bar{n}_0^2 = 0.41$, $\bar{n}_0^2 = 0.50$ and $\sigma_n =$ 0.30.

The σ_n value computed using formula (13) is 0.31. For individual latitude zones of the ocean the discrepancies between the actual $_n$ values and the values computed using (13) are of the order of σ_{σ_n} (Table 4). The established correlation between σ_n and $\overline{n}_0^2$ for cloud cover observations made four times a day in the North Atlantic is confirmed by observational data for other regions of the world ocean.

Table 5

Values of β Coefficient

t_a°C	n_0 0	1	2	3	4	5	6	7	8	9	10
−20	1,00	1,03	1,05	1,06	1,06	1,06	1,06	1,05	1,03	1,02	1,00
−10	1,00	1,02	1,03	1,04	1,04	1,04	1,04	1,03	1,02	1,01	1,00
0	1,00	1,01	1,02	1,03	1,03	1,03	1,03	1,02	1,02	1,01	1,00
10	1,00	1,01	1,02	1,02	1,02	1,02	1,02	1,02	1,01	1,01	1,00
20	1,00	1,01	1,01	1,02	1,02	1,02	1,02	1,02	1,01	1,00	1,00
30	1,00	1,00	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,00	1,00

Computations of the β coefficient were made using formulas (11)-(13). It has been established (see Table 5) that the β coefficient is dependent not only on the total cloud cover unit, but also on air temperature, as a result of the dependence $k_0(t_a)$. It should be noted that $\beta \geqslant 1$, as was noted in [14].

Thus, in computations of atmospheric radiation on the basis of mean values of the cloud cover unit in the absence of information on $\overline{n}_0^2$ the factor β must be introduced into the right-hand side of expression (1).

If, however, for computing the mean E_a values use is made of formula (8) it is necessary to introduce the factor β', similar in sense, determined using the formula

[N = low; B = up; C = mid]
$$\beta' = \frac{(1 + k_н \overline{n_н^2})[1 + k_{с+в}(\overline{n_0^2} - \overline{n_н^2})]}{(1 + k_н \overline{n}_н^2)[1 + k_{с+в}(\overline{n}_0^2 - \overline{n}_н^2)]}. \qquad (14)$$

These computations indicated that with an accuracy adequate for practical purposes it can be assumed that the coefficients β and β' are equal.

The results of computations of effective radiation by the described method were compared with data from independent measurements with a thermoelectric balancemeter at nighttime. For this purpose we used measurements made on ships of the Murmansk Administration of Hydrometeorology and Environmental Monitoring in the northern seas during 1958-1971 (3335 individual measurements). The mean E_{eff} value according to measurements was equal to 0.045 KW/m^2, and according to computations -- 0.048 KW/m^2. The order of magnitude of the divergence and its sign correspond to concepts on some understatement of the effective radiation registered with the thermoelectric balancemeter.

We note in conclusion that with use of the proposed method atmospheric radiation and the effective radiation of the ocean surface must be determined with an accuracy to 0.01 KW/m^2.

BIBLIOGRAPHY

1. Girdyuk, G. V., "Use of the GGO Radiometer for Measuring Effective Radiation of the Sea Surface," TRUDY GGO (Transactions of the Main Geophysical Observatory), No 206, 1967.

2. Girdyuk, G. V. and Malevskiy-Malevich, S. P., "Emissivity of the Water Surface," TRUDY GGO, No 206, 1967.

3. Girdyuk, G. V. and Malevskiy-Malevich, S. P., "Method for Computing Effective Radiation of the Ocean Surface," TRUDY GGO, No 297, 1973.

4. Girdyuk, G. V. and Kirillov, T. V., "Method for Computing the Radiation Balance Components for the Ocean Surface," METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 12, 1974.

5. Girdyuk, G. V., "Computation of Heat Losses of the Barents Sea Surface," PROBLEMY ARKTIKI I ANTARKTIKI (Problems of the Arctic and Antarctica), No 52, 1977.

6. Girdyuk, G. V., "Computation of the Radiation Balance of the Sea Surface Using Total Solar Radiation," TRUDY AANII (Transactions of the Arctic and Antarctic Scientific Research Institute), Vol 348, 1980.

7. Yegorov, B. N., "Dependence of Atmospheric Long-Wave Radiation on Cloud Cover in the Tropical Regions of the Atlantic," TROPEKS-72 (Tropeks-72), 1974.

8. Yegorov, B. N., "Influence of Cloud Cover on Atmospheric Radiation in the Tropical Zone of the Atlantic Ocean," TROPEKS-74 (Tropeks-74), Vol 1, 1976.

9. Kirillova, T. V., Girdyuk, G. V., Strokina, L. A. and Malevskiy-Malevich, S. P., "Comparison of Different Methods for Computing Components of the Radiation Balance of the Ocean Surface," METEOROLOGIYA I GIDROLOGIYA, No 11, 1976.

10. Malevskiy-Malevich, S. P., "Method for Making Radiation Measurements of Water Surface Temperature," TRUDY GGO, No 206, 1967.

11. Malevskiy-Malevich, S. P., "Determining the Bowen Ratio Over the Ocean," METEOROLOGIYA I GIDROLOGIYA, No 9, 1973.

12. Malevskiy-Malevich, S. P. and Petinova, A. Ya., "Method for Computing Atmospheric Radiation Over the Ocean ('Results of the 12th Voyage of the Scientific Research Ship 'Akademik Shirshov')," TRUDY DVNIGMI (Transactions of the Far Eastern Scientific Research Hydrometeorological Institute), No 56, 1975.

13. OKEANOGRAFICHESKIYE TABLITSY (Oceanographic Tables), Leningrad, Gidrometeoizdat, 1975.

14. Timofeyev, N. A. and Petrova, O. L., "Method for Computing Radiation Balance Components for the Ocean Surface," METEOROLOGIYA I GIDROLOGIYA, No 11, 1976.

15. U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD, Washington, D. C., Chief of Naval Operations, 1955-1959, 1965, Vols I-V, Vol XI.

UDC 551.465.7+551.515.2

INFLUENCE OF COLD SYNOPTIC OCEANIC EDDIES ON THE TRAJECTORY AND EVOLUTION OF TROPICAL CYCLONES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 9 Feb 81) pp 53-57

[Article by V. I. Byshev, candidate of physical and mathematical sciences, and V. G. Snopkov, candidate of geographical sciences, Institute of Oceanology, USSR Academy of Sciences]

[Text]

Abstract: Two cases of the passage of tropical cyclones over cold synoptic eddies in the open ocean are considered. It is shown that in both cases the hurricanes responded rapidly to the reduction in the transmittal of energy from the ocean into the atmosphere: they filled, there was a marked decrease in the velocity of movement and looping movement occurred. It is postulated that the looping trajectories are caused by the passage of the tropical cyclones over the cold oceanic eddies.

It is known from an analysis of empirical data and theoretical investigations that tropical cyclones are formed and persist due to the energy received from the ocean [3-5, 10]. The genesis of tropical cyclones with a warm center is associated with those regions of the world ocean where the water surface temperature exceeds 26°C [11]. Here the ocean is capable of imparting the maximum quantity of heat to the atmosphere. On the other hand, tropical cyclones never develop in places where the water surface temperature is less than 26°C, where air humidity is less than 40% and where vorticity at the lower levels of the troposphere has negative values. The formation and development of tropical cyclones requires the constant influx of heat, momentum and water vapor from the atmospheric boundary layer [1]. These facts indicate that tropical cyclones are extremely sensitive to small changes in temperature and humidity.

Earlier it was noted in the literature that there is a correlation between the frequency of recurrence of tropical cyclones and water temperature anomalies. For example, Jordan [5] demonstrated that the mean monthly positive anomalies of 1°C are frequently observed in the region of formation of tropical cyclones in the Western Atlantic. Miller [10], in the example of study of hurricane Donna, demonstrated that for the attenuation of a hurricane the factor of primary importance is the disappearance of an oceanic heat source, not an increase in dissipation under the influence of surface friction. Accordingly, the passage of a tropical cyclone over a cold water surface or the intrusion of cold dry air into the region of a tropical cyclone at the lower levels leads to its attenuation.

Academician Shuleykin [7], modeling the evolution of a tropical cyclone, indicated that there is some critical surface water temperature above which a tropical cyclone receives more energy than is expended on its dissipation, whereas with a water temperature below the critical point in a tropical cyclone the energy expenditure on dissipation exceeds its receipt from the ocean, as a result of which the tropical cyclone begins to weaken.

At the present time in the practical prediction of movement of tropical cyclones use is made of the "steering current" rule, according to which a disturbance moves together with the "steering current" in the middle troposphere, that is, the atmosphere controls the movement of a tropical cyclone. Sometimes there are unusual trajectories when a tropical cyclone experiences a looping movement. In this case the "steering current" rule is not operative and the prediction of movement of a tropical cyclone becomes the central problem. Below we will examine two cases of the passage of hurricanes over a cold synoptic disturbance in the ocean and we will trace their behavior. First we will cite the necessary information on the cold oceanic synoptic disturbances.

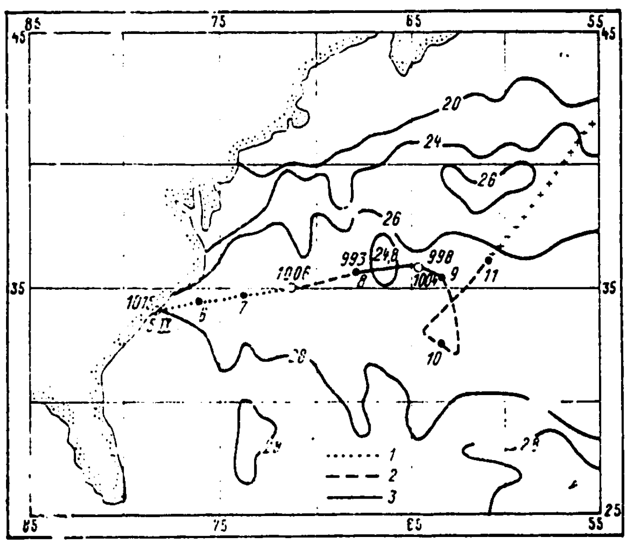

Fig. 1. Map of mean monthly water surface temperature for September 1977 and the trajectories of movement of hurricane Clara. 1) tropical low, 2 tropical storm, 3) hurricane.

Investigations of synoptic variability in the ocean (Poligon-70, MODE, POLIMODE) made it possible to discover eddy disturbances in the ocean with a diameter of 100 km or more. Among these synoptic disturbances were rings and eddies in the open ocean. The rings are warm and cold. They are formed as a result of the dynamic instability of a jet current, have a thickness in depth of about 1000 m and usually are transported to the west or southwest with a variable velocity of several kilometers per day and persist for two years or more. Cold rings are observed in the Atlantic and Pacific Oceans to the south of the Gulf Stream and Kuroshio. The temperature and salinity of the rings is usually below the temperature and salinity of the surrounding water by 3-4°C and by several tenths ‰.

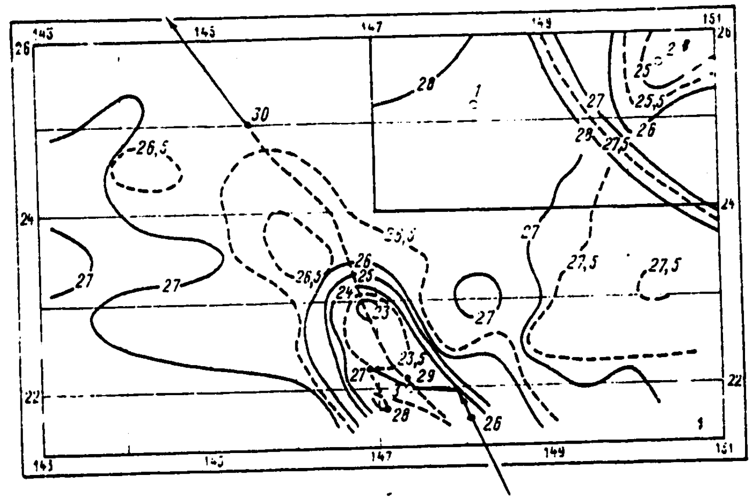

Fig. 2. Map of water surface temperature for period 1-6 August 1978 and trajectory of movement of hurricane Virginia. Solid curve -- typhoon, dashed curve -- tropical low. The insert shows the water surface temperature for the period 23-28 June 1978.

The general situation is such that the temperature field of a hurricane is formed due to the receipt of apparent and latent heat from the ocean both from the periphery and from the internal region of a hurricane. Accordingly, moving over the cold water, the hurricane is deprived of that part of the energy which could be received from the region occupied by cold water. As a result, the hurricane will expend more energy on dissipation than it receives from the ocean and begins to attenuate.

Case 1. Hurricane Clara was observed in the Atlantic Ocean during the period 6-12 September 1977. It developed on the east coast of the United States from a tropical low. Figure 1 shows the trajectory of the hurricane and also the mean monthly surface temperature of the ocean in September 1977 [9]. It can be seen that between 8 and 9 September the trajectory of hurricane Clara passed over a cold ring in which the water temperature was 24.8°C, which differs from the surrounding water by 2°C. The temperature contrast must evidently exceed 2°C. Due to the mobility of the ring and monthly temperature averaging it is appreciably smoothed. The spatial scale of the ring is more than 100 km.

A tropical low, moving over warm water with a temperature higher than 27°C, on 7 September was transformed into a tropical storm and on 8 September it became a hurricane. Then, with passage of the hurricane onto the cold ring, it began to weaken rapidly. The pressure at its center already on the first day increased by 12 mb, the intensity decreased and the hurricane was transformed into a tropical storm. Simultaneously with weakening of the hurricane there was a change in the trajectory and a decrease in the velocity of movement. Between 9 and 11 September the tropical storm made a loop and then moved in a northeasterly direction. Thus, the passage of the hurricane onto a local cold formation led to a rapid change in its intensity, velocity and direction of movement.

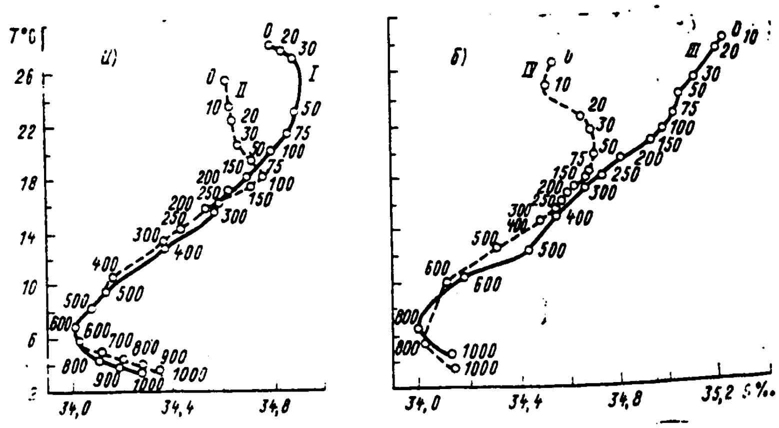

Fig. 3. T,S curves at point 3(a) and at points 1 and 2 (b) (see Fig. 2). I) before passage of typhoon, II) after passage of typhoon, III) at point 1, IV) at point 2.

Case 2. In 1978, in the northwestern part of the Pacific Ocean, under the "Tayfun-78" program [6], investigations were made in the region 10-35°N and 125-170°E. A hydrological survey in the region 28°N and 143-151°E from 23 through 28 June made it possible to detect [6] a cold cyclonic formation in the northeastern sector. Its position is indicated in the insert in Fig. 2. The temperature and salinity of the surface water in the cold disturbance (Fig. 2, point 2) were lower by 3°C and 0.6°/oo than the temperature and salinity of the surrounding water (Fig. 2, point 1). The horizontal scale of the cold disturbance (Fig. 2) is more than 100 km.

Figure 3b, on the basis of data in [6], gives T,S curves characterizing the structure of waters in the cold cyclonic formation (curve IV) and the structure of the surrounding water (curve III). It can be seen that the thickness of the cold cyclonic disturbance attains 1000 m in depth. The presence of a cold cyclonic disturbance and its direction of movement, in accordance with [6], was traced from Japanese daily satellite cloud cover maps in the form of a cloudless zone. These maps were received daily in the period from July through September.

An analysis of cloud cover maps indicated that the cloudless zone moved in a southwesterly direction. Assuming that the velocity of movement of a cold cyclonic formation is about 5-5.5 miles/day [2], it can be expected that after a month, that is, about 26 July, it would move from the region 25-26°N and 150-151°E to the region 23-24°N and 148-149°E (position of the postulated center on 26 July). Typhoon Virginia approached this region on 26 July. Here it was transformed from a typhoon into a tropical storm. The pressure at its center increased from 980 to 990 mb.

On 27 July, typhoon Virginia, passing over the cold disturbance, was filled (the pressure increased by 10 mb), was transformed into a tropical cyclone, changed direction of movement and lost velocity. On 28 July it began to drop slowly to the south, to the warmer water, where it again began to deepen; pressure at its center decreased to 980 mb. On 29 July the tropical cyclone continued to develop, acquiring a velocity of about 15 km/hour and over a 24-hour period was displaced to the northwest 3° in latitude. On 30 July at 25°N the tropical cyclone passed over the warm water and was again transformed into a hurricane.

Figure 2 shows the distribution of water surface temperature according to data of a repeated survey from 1 through 6 August, as well as the trajectory of movement of hurricane Virginia. Figure 3a shows the T,S curves for point 3 (see Fig. 2) with the coordinates 22°N and 147°20'E before (I) and after (II) passage of the typhoon [6]. The T,S curves for the cold cyclonic formation in Fig. 3b (IV) and the T,S curves in the wake of the typhoon in Fig. 3a (II) have much in common: in the upper 150-m layer the T,S curves for temperature and salinity duplicate each other well. This fact, in our opinion, is evidence that the cold cyclonic formation (Fig. 2, insert) after 40 days could be in the region 22°30'N and 147°E, that is, in the place through which the typhoon has passed. Thus, in this case as well the passage of a hurricane, Virginia, over a cold cyclonic formation, which over the course of 40 days had moved southwestward for a distance of about 400 km, led to a rapid change in its intensity, velocity and direction of movement.

The two cases of the influence of cold synoptic disturbances in the ocean on tropical cyclones considered above give us basis for assuming that the looping trajectories of tropical cyclones in the open ocean are caused by the passage of a tropical cyclone over a cold oceanic disturbance.

In order to confirm our assumption it is necessary to have statistics on similar cases. Unfortunately, there are only a few known cases of the passage of a tropical cyclone over a cold oceanic disturbance. In addition, there is no synchronous information on a tropical cyclone and synoptic disturbances in the ocean. According to the data in [3], in the region of the Philippine Sea over a period of 15 years (1953-1968) there was an annual average of 12-13 typhoons, one or two having a looping trajectory. Without rejecting the existence of an atmospheric influence on looping trajectories of tropical cyclones it can also be assumed that the passage of a tropical cyclone over a cold synoptic disturbance is the reason for its looping trajectory. In order to supplement our knowledge concerning the mutual influence of atmospheric and oceanic eddies in the future it is desirable to carry out experimental investigations in the corresponding regions of the world ocean.

BIBLIOGRAPHY

1. Ivanov, V. N., Mikhaylova, L. A. and Nekrasov, I. V., "Some Statistical Properties of the Phenomenological Parameters of Cyclogenesis in the Tropical Zone," TAYFUN-78 (Typhoon-78), Leningrad, Gidrometeoizdat, 1980.

2. Kort, V. G. and Pavlova, Yu. V., "Structure of the Field of Mesoscale Eddies According to Data From Hydrological Surveys," OKEANOLOGICHESKIYE ISSLEDOVANIYA (Oceanological Research), No 30, GIDROFIZICHESKAYA EKSPEDITSIYA POLIMODE (POLIMODE Hydrophysical Expedition), Moscow, Sovetskoye Radio, 1979.

3. Mamedov, E. S. and Pavlov, N. I., TAYFUNY (Typhoons), Leningrad, Gidrometeoizdat, 1974.

4. Pal'men, E. and N'yuton, Ch., TSIRKULYATSIONNYYE SISTEMY ATMOSFERY (Atmospheric Circulation Systems), Leningrad, Gidrometeoizdat, 1973.

5. Ril', G., TROPICHESKAYA METEOROLOGIYA (Tropical Meteorology), Moscow, IL, 1965.

6. TAYFUN-78 (Typhoon-78), Leningrad, Gidrometeoizdat, 1980.

7. Shuleykin, V. V., RASCHET RAZVITIYA, DVIZHENIYA I ZATUKHANIYA TROPICHESKIKH URAGANOV I GLAVNYKH VOLN, SOZDAVAYEMYKH URAGANAMI (Computation of the Development, Movement and Attenuation of Tropical Hurricanes and Main Waves Created by Hurricanes), Leningrad, Gidrometeoizdat, 1978.

8. Gray, W. M., "Global View of the Origin of Tropical Disturbances and Storms," WEATHER REV., Vol 96, No 10, 1968.

9. GULFSTREAM, Vol III, No 9, 1977.

10. Miller, B. I., "On the Filling of Tropical Cyclones Over Land," HURRICANE RES. PROJ. REPT., No 66, 1963.

11. Palmen, E., "On the Formation and Structure of Tropical Hurricanes," GEOPHYSICA, Helsinki, 3, 1948.

UDC 551.465

PHYSICAL STRUCTURE OF THE OCEAN SURFACE LAYER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 17 Feb 81) pp 58-66

[Article by K. N. Fedorov, doctor of physical and mathematical sciences, Institute of Oceanology, USSR Academy of Sciences]

[Text]

Abstract: A study of the structure of the ocean surface layer under different hydrometeorological conditions makes it possible to discriminate at least four characteristic physical regimes of the upper layer in the ocean: 1) intensive wind-wave mixing, 2) Langmuir circulation, 3) intensive solar heating during calms and periods of weak winds (with modulations by internal waves and without them), 4) surface freshening by precipitation. It is shown that the spatial variability of temperature of the ocean surface (TOS), vertical thermal structure and heat content of the upper layer have a different character in different regimes, which must be taken into account when selecting the horizon for measuring TOS by contact methods and when comparing contact and satellite TOS data. The need for further investigations in this field is emphasized.

In standard hydrological measurements at sea the upper bathometer is usually placed at the horizon 1 m. In principle no one has ever precisely measured the distance from the sea surface to the first bathometer and in fact it cannot be precisely measured because the length of the bathometer itself is commensurable with this distance. In order for the bathometer not be exposed when it is subjected to the swell and waves it is usually submerged with a sort of safety factor, but in calms it is situated as close to the surface as possible. In any case, in tables of standard oceanographic data this horizon is designated 0 m. It is implicitly assumed that the structure and variability of temperature and salinity in a layer with a thickness of several meters near the ocean surface can be neglected. But can this always be done?

Oceanologists have long known that the upper quasihomogeneous layer (UQL) of the ocean in actuality not everywhere and not always is homogeneous or even quasihomogeneous [9, 13]. However, scientists have been interested in the thin surface layer of the ocean only recently. The highly promising prospects for the use of satellite methods in mapping the temperature of the ocean surface (TOS) have required a detailed knowledge of the characteristics and an understanding of the physical nature of the spatial-temporal variability of the TOS under the most different geographic, weather and climatic conditions.

In connection with the development of methods for remote investigations of the ocean, during recent years special attention has been devoted to the heat-exchange surface layer, which in most cases with adequate basis can be called the "cold surface film" of the ocean. The thickness of this layer does not exceed 5-8 mm, and in most natural situations it is actually colder than the underlying layers [4-6]. However, it soon became clear that the "cold film" alone cannot lead to substantial differences between the observed parameters of the radiation TOS and the observed kinetic temperature at a depth of 1 m or more. In the surface layer of the ocean with a thickness of several meters there was found to be a complex structure and an increased spatial-temporal variability of many hydrophysical characteristics. It was established that the greatest variability of thermal structure is observed during intensive solar heating in calm weather or in the presence of light winds [12] and is associated for the most part with volumetric absorption of solar radiant energy, heat losses in evaporation, convection, modulation of the surface layer by internal waves and the peculiarities of surface salt stratification. The high variability of salinity in the surface layer is determined primarily by the long-prevailing consequences of its freshening by rainwater. Horizontal differences in salinity of about $1^{\circ}/oo$ per kilometer arise in the upper meter layer of the ocean in the absence of intensive wind mixing [3].

The appearance of a hydrostatically stable thermal or salt stratification near the surface gives rise to a sort of "blocking effect" which prevents the downward propagation of wind-wave and convective turbulent energy into the thickness of the UQL. A stable stratification extinguishes the earlier developing turbulence and can impede the development of shear instability within the UQL. Since the variability of the thermal structure in the surface layer of the ocean most frequently has a clearly expressed diurnal variation, the intensity of turbulence within the UQL also should experience a diurnal variation, as is confirmed by observations [10]. However, the salt stratification not only is less subject to diurnal changes, but can also substantially disrupt the diurnal variation of changes in thermal structure, leading to prolonged overheating of the surface layer persisting over the course of natural synoptic periods.

The discovered variability is not an anomalous or exotic phenomenon. It is characteristic during the entire year for the entire Intertrades zone of the world ocean, for extensive subtropical regions where the velocity of the Trades decreases to 5 m/sec, and over the summer period, also in the middle latitudes. Altogether the regions where such a variability can be observed constitute more than 40% of the area of the world ocean. Such regions as the Sargasso Sea in the Atlantic, the western part of the Pacific Ocean and the northern part of the Indian Ocean are especially characteristic from the point of view of an increased variability of the thermohaline structure of the upper layer of the ocean.

In order to demonstrate graphically everything which has been stated above in specific examples from observations it is first necessary to examine some important parameters of the surface layer of the ocean associated with heat exchange between the ocean and the atmosphere. Assume that H denotes the thickness of the UQL and h the thickness of the layer in which convection develops under the influence of heat losses from the surface. It is convection which is the principal source of kinetic turbulent energy in the QHL in windless or slightly windy weather. At nighttime, as a rule, h = H and convection carries turbulent energy directly to the lower boundary of the QHL, which deepens under the influence of turbulent entrainment. Thus, H in the nighttime hours can increase. During the daytime, when the receipt of solar heat exceeds the sum of losses due to long-wave radiation, evaporation and contact heat exchange, $h < H$. Since all heat losses for all practical purposes occur from the ocean surface (z = 0) and the absorption of incoming solar radiation in the upper layer of the ocean has a volumetric character, this absorption can be represented as some distributed source and beneath the ocean surface there will be some horizon D at which the total heat flux is equal to zero. At this horizon, accordingly, the vertical temperature gradient dT/dz is equal to zero and a layer with a stable thermal stratification also arises. The depth D is called the depth of thermal compensation [16]. It can be assumed that during the daytime h = D. The D value does not remain constant over the course of 24 hours because it is dependent on the intensity of the incoming solar radiation and on the intensity of the total losses of heat through the ocean surface. Since the solar heating maximum is usually observed at 1500-1600 hours local solar time, the thickness of the convective layer at this time in the absence of salt stratification is minimum and does not exceed 10 cm. It attains 1 m by 1600 hours [1] and then rapidly increases, at nighttime propagating to the entire QHL. With sunrise the h and D values again begin to decrease, closing the diurnal cycle by 1500-1600 hours. Radiation models can be constructed for computing the diurnal variation of D [11, 16].

The existence of a depth of thermal compensation is not some theoretical abstraction. A detailed measurement of vertical temperature profiles in the upper layer of the ocean with a thickness of 10 m by means of a special floating-up probe designed by Vershinskiy and Solov'yev (Institute of Oceanology, USSR Academy of Sciences) [1] repeatedly revealed the near-surface presence of a homogeneous layer with a thickness of about several tens of centimeters with a small temperature inversion directly beneath this layer (Fig. 1). This is also the daytime convective layer, whose lower boundary virtually coincides with the depth of thermal compensation.

The small thickness of the convective layer in calm weather when there is intensive solar heating and absence of other sources of turbulent energy in the QHL has the following result: the greatest increase in heat content occurs in the thin surface layer with a thickness of only 0.5-1.0 m. The vertical temperature profile acquires the form shown in Fig. 2 and the temperature difference in the surface layer from the temperature at a depth of 7-10 m by 1600-1900 hours local solar time can attain 3°C [14]. The stability of thermal stratification in the layer below the temperature maximum, that is, at the horizons 2-5 m, can in this case be characterized by a Väisälä-Brent frequency N of about $(3\text{-}4)\cdot 10^{-2}$ sec^{-1}. Under these conditions the diurnal thermocline is sharper than the seasonal and main thermoclines. With an increase in the thickness of the layer affected by convection there is a gradual evening-out of the T(z) profile vertically; at nighttime a virtually complete homothermy develops within the limits of the entire QHL.

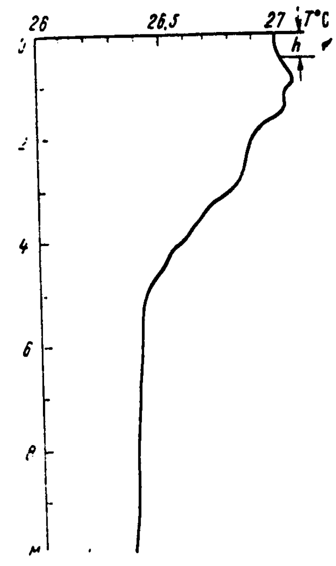

Fig. 1. Vertical profile of temperature in the Sargasso Sea on a summer day with little wind. In the upper part of the profile there is a daytime convective layer with a thickness h. (Measurements by the author made using a floating-up probe on the 27th voyage of the scientific research ship "Akademik Kurchatov"). At the time of the measurements (21 September 1978, 1449 hours) the weather was cloudless, the wind was 3 m/sec, air temperature was 26.0°C and humidity was 76%.

The appearance of a stable salt stratification near the surface as a result of showers additionally complicates the picture. The measurements which were made indicated that when there is a relatively weak wind showers with a duration of 1-2 hours and an intensity of 20 mm/hour or more there can be a freshening during the falling of the shower of a thin (up to 1 m thick) layer near the ocean surface by 0.5-1°/oo, which considerably exceeds the usual local variability of salinity in the upper layer in the absence of rain. Brief lighter showers reduce salinity near the ocean surface by 0.2-0.3°/oo [3]. The salinity (and density) jump at the lower boundary of the freshened spot, impeding turbulent and convective heat exchange with the lower-lying layers, during the daytime leads to extremal heating of the surface layer. For example, in the summer of 1978 in the Sargasso Sea (region of the POLIMODE experiment) during calm weather the water temperature near the surface in the freshened spots attained 29-32°C, whereas at adjacent points, where rain did not fall, it did not exceed 27.5-28.5°C [3]. Clearly the case of spatial-temporal variability of TOS with an amplitude greater than 3°C is completely not characteristic for the mean climatic conditions in this region in summer.

The density jump at the lower boundary of freshened spots can be characterized by the values of the Väisälä-Brent frequency of about $(1\text{-}3)\cdot10^{-2}\,\text{sec}^{-1}$. The sharper vertical gradient of salinity (density) near the surface corresponds to more intensive daytime heating. This can be seen clearly in Fig. 3, which shows three profiles of deviations of temperature $\Delta T(z)$ and salinity $\Delta S(z)$ from the corresponding T and S values at the horizon 10 m in the Sargasso Sea in the summer of

1978. The measurements were made using a special method using the "AIST" hydrophysical probe [3]. In accordance with the same physical logic the freshened spots are more intensively cooled at nighttime in comparison with the surrounding waters as a result of a forced limitation on the thickness of the freshened layer affected by convection (see Fig. 4 and also [3]). Thus, showers lead to the appearance of significant horizontal temperature inhomogeneities in the surface layer having a spatial scale of about 1-10 km.

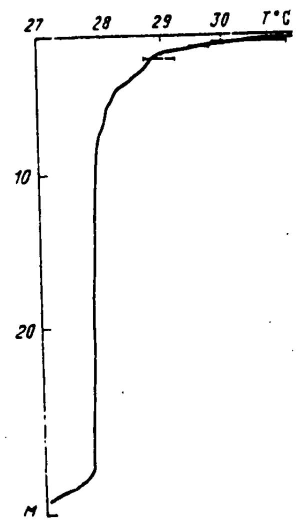

Fig. 2. Vertical temperature profile in the upper 10-m layer of the Sargasso Sea typical for conditions of intensive solar heating according to measurements made by V. T. Paka and the author (27th voyage of the scientific research ship "Akademik Kurchatov" on 25 August 1978 at about 1600 hours). The horizontal lines near the surface indicate the limits of temperature variability on the basis of measurements from a float.

Precipitation by no means is the only factor favoring the formation of horizontal inhomogeneities of TOS. Another and evidently more universal mechanism for the formation of horizontal inhomogeneities of TOS of a kilometer scale is the modulation of the thickness of the heated surface layer of the ocean by internal waves of the seasonal thermocline, manifested very appreciably during calm weather and when there are weak winds at the hours of intensive solar heating [12]. The fact is that the heat accumulated as a result of solar heating in the surface layer of the ocean enters as a passive admixture relative to the convergent and divergent movements generated in this layer by internal waves. We note that in a similar way internal waves can modulate the thickness of the freshened surface layer and the thickness of spots of plankton or its concentration, etc. The amplitudes of inhomogeneities of TOS associated with modulation of the heated layer by internal waves can attain 1-2°C. At the edges of the warm and cold spots there are very sharp horizontal temperature gradients (up to 2 or more °C per 1 km). Examples of the characteristic registry of "calm weather temperature inhomogeneities" obtained during the towing of a temperature sensor at the horizon 0.15 m in the summer of 1977 in the Sargasso Sea are shown in Fig. 5. "Calm weather inhomogeneities" arise most frequently at 1000-1100 hours local solar time, and sometimes later, attain a maximum amplitude at about 1500 hours, that is, by the time of maximum heating of the surface layer, and virtually completely disappear by 2100-2200 hours. In the case of strong heating inhomogeneities of a kilometer scale are also registered at the horizon 3-4 m [12], whereas the smaller inhomogeneities with a scale of about 100 m and an amplitude of several tenths of a degree accompanying them, seen easily in Fig. 5a, are observed only near the surface of the sea and disappear completely after 1500 hours.

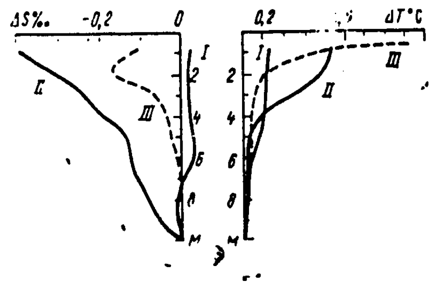

Fig. 3. Three types of dependence of vertical temperature profile in surface layer of ocean on salt stratification. The ΔT and ΔS values represent deviations from the temperature and salinity values at the horizon 10 m. I) weak salt stratification, II) moderate salinity gradient in entire layer, III) sharp salinity gradient near surface. Measurements made by the author on the 27th voyage of the scientific research vessel "Akademik Kurchatov."

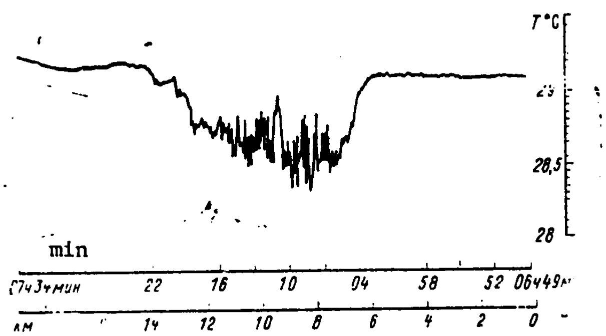

Fig. 4. "Track" of rain cooling during night in the surface layer of the ocean registered at 0700 hours near Cuba using a temperature sensor towed from the scientific research vessel "Akademik Kurchatov" at the horizon 0.15 m (27th voyage, 16 September 1978).

An evaluation of the characteristic horizontal scale L of temperature spots made in [12] in accordance with the results [8] of a theoretical analysis of modulation of the fields of movement and a passive impurity in the surface layer by a random field of internal waves gave for the observation region a value L≃1200 m, which coincides well with the results of in situ measurements. Temperature inhomogeneities with a scale of about 100 m are associated, in all probability, with differences in the intensity and depth of penetration of daytime convection as a result of the presence at the surface of spots of surface-active substances, as well as fluctuations of the position of the temperature sensor vertically during towing in a layer with a sharp temperature gradient.

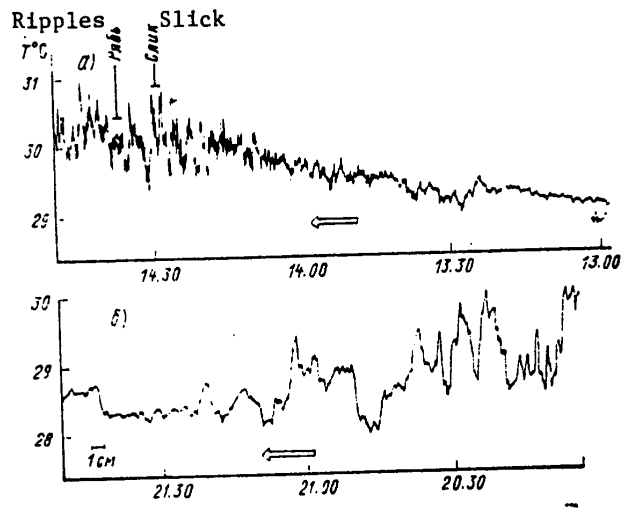

Fig. 5. Thermal inhomogeneities during calm weather registered with a towed temperature sensor at the horizon 0.15 m on the 25th voyage of the scientific research ship "Akademik Kurchatov" in the Sargasso Sea in August 1977.

In addition to the regimes associated with surface freshening and modulation of the thickness of the heated layer by internal waves and characteristic for windless weather or weather with little wind, it is common to observe a regime of circulations or Langmuir cells setting in with winds from 3 to 10 m/sec. Langmuir circulations are a result of interaction between drift currents and waves and are manifested at the ocean surface in the form of many parallel convergence bands elongated along the wind or at a small angle to it. The distance between the convergence bands is approximately equal to the thickness of the UQL and can vary from 5 to 100 m. Divergence bands are situated between the the convergence bands over the ascending branches of the vertical circulations.

In a transverse vertical section of a Langmuir circulation there are closed cells of streamlines penetrating into the depths most frequently (but not always!) to this lower boundary of the mixed layer. When there is a weak wind and intensive solar heating the water temperature in the convergence bands is greater than in the intervals [7]. The heat carried downward by the descending currents creates in a layer with a thickness of several meters a bandlike thermal structure (Fig. 6). Since in this case wind and wave mixing is also operative, the amplitudes of the horizontal changes in temperature in these bandlike structures are not always as great as in calm weather inhomogeneities and evidently most frequently do not exceed 0.5-0.6°C. As indicated by Fig. 6, illustrating the results of our measurements in Langmuir cells in the Sargasso Sea in the summer of 1978, the heat content of the layer with a thickness of 7 m can differ in the convergence and divergence bands by approximately 0.3-0.4 of the daytime sum of direct solar radiation. Thus, the Langmuir circulations are an extremely effective mechanism for the redistribution of heat horizontally and its transfer into the depths and with intensive development can completely determine the position of the diurnal thermocline with depth.

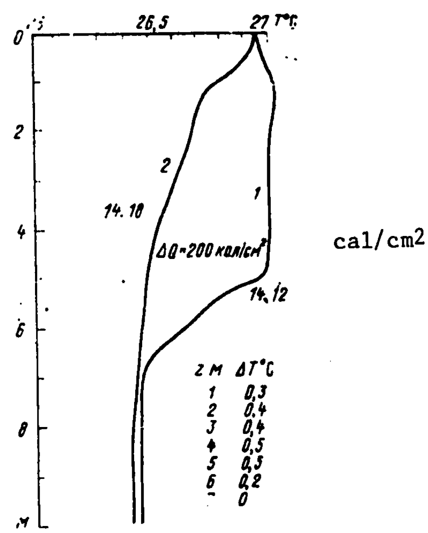

Fig. 6. Distribution of temperature profile in Langmuir cells. Measurements by the author on 21 September 1978 in Sargasso Sea (27th voyage of the scientific research vessel "Akademik Kurchatov"). The difference in the heat reserve between regions of convergence and divergence is indicated between the profiles. Weather: cloudless, wind 3-4 m/sec, air temperature 26.0°C. 1) in convergence band, 2) between convergence bands.

Thus, in the considered regions of the ocean it is possible to discriminate at least four sharply differing regimes of the upper layer in the ocean:

1. A regime of intensive wind-wave mixing (wind velocity $u_{10} >$ 8-10 m/sec).

2. A regime of Langmuir circulations (u_{10} from 3 to 10 m/sec).

3. A regime of intensive solar heating in calm weather and weather with little wind (u_{10} from 0 to 3-5 m/sec) with modulations of the heated layer by internal waves and in the absence of internal waves.

4. A regime of surface freshening by precipitation.

Accordingly, by the light part of the day the diurnal thermocline in different regimes can be situated at different horizons from 2-5 to 30-40 m. The least deep diurnal thermocline (2-5 m) with sharp vertical temperature gradients is usually associated with a strong freshening of the surface layer by precipitation. Langmuir cells and intensive wind-wave mixing can be responsible for the propagation of daytime heating to 30-40 m, where the diurnal thermocline becomes very weak and virtually merges with the seasonal thermocline. The distribution of the diurnal receipts of solar heat, at the considered latitudes being about 500-600 cal/cm^2 [15], in a layer of such different thickness also gives a range of local variability of TOS from one regime to the next of 3°C. The convergent and divergent currents, caused by Langmuir circulations and internal waves in the surface layer, horizontally redistribute the heat absorbed near the surface in the course of the light part of the day. We observed situations when, for example, by the end of the day due to the effect of internal waves the difference between the heat content of the upper layer of the ocean at two adjacent points at a distance of only about 1 km attained the totals of the solar radiation absorbed during the day. In this case the amplitude of the spatial variability of TOS can easily attain 2°C.

The data cited above indicate that allowance only for the "cold surface film" does not solve the problem of an adequate correction of the measured values of the radiation TOS for the purpose of obtaining information reflecting the changes in the heat content of the upper layer of the ocean. The correction ΔT_0 due to the film can be computed relatively easily from the known or predicted hydrometeorological conditions using available formulas [5, 6]. However, these same conditions also determine the specific regime of the upper layer with which in turn some distribution of solar heat entering the ocean is associated. Unfortunately, there are still no good models describing the regimes which are most complex in structure.

It also follows from the data cited above that the measurements of TOS made using contact apparatus situated at arbitrary horizons beneath the ocean surface can provide inadequate material for judgments concerning the heat content of the upper layer of the ocean, for comparison with satellite data or for their tie-in if one does not take into account the peculiarities of structure of the surface layer characteristic of the specific regime in which the measurements are made [2].

In connection with what has been cited above it is entirely desirable and timely to formulate the problem of a many-sided intensification of investigations (by the personnel of several scientific institutes) of the range of problems dealt with here, which it would be fitting to give the arbitrary name "physical oceanology of the upper meter of the ocean."

The formulation of the necessary investigations meets with serious methodological and instrumental difficulties because for making the desired in situ measurements in the surface layer of the ocean the standard measurement instruments and methods are not suitable. For a number of instruments, such as for hydrophysical STD probes, a special measurement method is required which takes into account the rolling and drift of the ship, which introduce disturbances both in the measurements themselves and in the structure of the medium in which the measurements are made. Many measurements could be made while the vessel is proceeding on course, but the instrumentation registering not only temperature, but also salinity near the ocean surface, necessary for this purpose, is completely lacking. None of these matters have been discussed to any extent from either the methodological point of view or in themselves. One of the purposes of this article is to stimulate an active discussion of the mentioned problem.

BIBLIOGRAPHY

1. Vershinskiy, N. V. and Solov'yev, A. V., "Probe for Investigations of the Surface Layer of the Ocean," OKEANOLOGIYA (Oceanology), Vol 17, No 2, 1977.

2. Ginzburg, A. I., "Methodological Problems in Measurements of Temperature and Salinity in the Boundary Layer of the Ocean," METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 4, 1981.

3. Ginzburg, A. I., Zatsepin, A. G., Sklyarov, V. Ye. and Fedorov, K. N., "Effects of Precipitation in the Ocean Surface Layer," OKEANOLOGIYA, Vol 20, No 5, 1980.

4. Ginzburg, A. I., Zatsepin, A. G. and Fedorov, K. N., "Fine Structure of the Thermal Boundary Layer in Water at the Water-Air Discontinuity," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA (News of the USSR Academy of Sciences: Physics of the Atmosphere and Ocean), Vol 13, No 12, 1977.

5. Ginzburg, A. I. and Fedorov, K. N., "Water Cooling From the Surface During Free and Forced Convection," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, Vol 14, No 1, 1978.

6. Ginzburg, A. I. and Fedorov, K. N., "Thermal State of the Boundary Layer of Cooling Water With Transition From Free to Forced Convection," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, Vol 14, No 7, 1978.

7. MODELIROVANIYE I PROGNOZ VERKHNIKH SLOYEV OKEANA (Modeling and Prediction of the Upper Layers of the Ocean), Leningrad, Gidrometeoizdat, 1979.

8. Monin, A. S. and Piterbarg, L. I., "Statistical Description of Internal Waves," DOKLADY AN SSSR (Reports of the USSR Academy of Sciences), Vol 234, No 3, 1977.

9. Monin, A. S. and Fedorov, K. N., "Fine Structure of the Upper Layer of the Ocean," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, Vol 9, No 4, 1973.

10. Paka, V. T. and Fedorov, K. N., "Influence of Thermal Structure of the Upper Layer of the Ocean on the Development of Turbulence," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, 1981 (in press).

11. Solov'yev, A. V., "Fine Thermal Structure of the Surface Layer of the Ocean in the POLIMODE-77 Region," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, Vol 15, No 7, 1979.

12. Fedorov, K. N., Ginzburg, A. I. and Piterbarg, L. I., "Physical Nature of 'Calm Weather Inhomogeneities in the Temperature Field of the Ocean," OKEANOLOGIYA, Vol 21, No 2, 1981.

13. Fedorov, K. N., Plakhin, Ye. A., Prokhorov, V. I. and Sedov, V. G., "Characteristics of Thermohaline Stratification in the Region of the Polygon in the Tropical Atlantic," ATLANTICHESKIY GIDROFIZICHESKIY POLIGON-70 (Atlantic Hydrophysical Polygon-70), Moscow, Nauka, 1974.

14. Bruce, J. G. and Firing, E., "Temperature Measurement in the Upper 10 m With Modified Expendable Bathythermograph Probes," J. GEOPHYS. RES., Vol 79, No 2, 1974.

15. Fedorov, K. N., "On the Summer Daily Heating and Diurnal Heat Budget of the Upper Ocean Layer," STUDI IN ONORE DI GIUSEPPINA ALIVERTI, Napoli, 1972.

16. Woods, J. D., "Diurnal and Seasonal Variations of Convection in the Wind-Mixed Layer of the Ocean," QUART. J. ROY. METEOROL. SOC., Vol 106, No 449, 1980.

UDC 551.466.31

ANGULAR SPECTRUM OF WIND WAVES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 6 Jan 81) pp 67-71

[Article by I. P. Trubkin, candidate of physical and mathematical sciences, State Oceanographic Institute]

[Abstract] The wave-covered sea surface is anisotropic. The properties of the wave-covered surface, described by statistical methods, especially anisotropy, are reflected in the angular spectrum, characterizing the statistical distribution of the energy of waves in the direction of their propagation. Present-day concepts concerning the form of the angular spectrum function are based exclusively on limited experimental data. Accordingly, in this article the author has made an attempt at an analytical determination of this function within the framework of a linear probabilistic model of wind waves. An analytical expression is derived for the angular spectrum which reliably characterizes the statistical distribution of the energy of waves in the direction of their propagation. It is shown that the angular distribution of wave energy is determined by the angular distribution of the mean square absolute value of the vector of horizontal displacements of water particles at the wave-covered sea surface; the function $S_z(\theta)$ characterizes these distributions. An example of computations by the described method is illustrated using data from in situ measurements in the Caspian Sea. It is shown that in the considered case of waves developing in deep water (22 m) a large part of the wave energy is propagated in the direction of the waves. In the region of the maximum of the $S(\theta)$ function the distribution of wave energy is narrow (angular width at the 0.5-level is about 35°). A minimum energy is characteristic of the components of the waves propagating in a direction perpendicular to the general direction. The values of the angular spectrum also indicate that in the considered case the wave field contains components propagating in a direction counter to the general lirection with an energy approximately an order of magnitude less than the minimum value of the angular spectrum. Figures 2; references: 3 Russian.

UDC 551.521.31:627.8(282.247.32)

SOLAR ENERGY SUPPLY TO DNEPR CASCADE RESERVOIRS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 7 Jan 81) pp 72-78

[Article by V. M. Shmakov, candidate of technical sciences, Hydrobiology Institute, Ukrainian Academy of Sciences]

[Abstract] The solar energy incident on land or water surfaces is measured by actinometers, but in the Dnepr basin in the Ukraine there are only seven actinometric stations and they are distributed nonuniformly and without any particular relationship to reservoirs. Continuous measurements of solar energy are not made at a single one of the reservoirs in the Dnepr cascade. However, it has been established that total solar radiation is an extremely stable characteristic. An analysis of the results of observations at the seven mentioned stations revealed an entirely satisfactory correlation of the monthly radiation sums with correlation coefficients 0.93-0.98. This indicated that it was possible to use the data from these observations for calculating the solar energy incident on the reservoir surfaces. The collected data revealed that solar energy exerts a great influence on hydrobiological processes in water bodies, governs their thermal regime and affects the formation of water quality. Photosynthetically active radiation is of special importance because it directly controls the quantity of primary production of phytoplankton. The investigations revealed a dependence of the quantity of solar energy on solar altitude, atmospheric transparency and cloud cover. Conversion factors from total solar radiation to photosynthetically active radiation make it possible to compute these quantities. The propagation of photosynthetically active radiation in water is influenced by solar altitude and also by water color and transparency. In the reservoirs of the cascade there is a decrease in the absorption of solar energy by the water and its color and an increase in transparency from the upper (Kiyevskoye) to the lower (Kakhovskoye) reservoirs. The distribution of photosynthetically active radiation with depth in the reservoirs of the cascade occurs in conformity to curves close to hyperbolic, whose parameters are water transparency and solar altitude. The depth of penetration of photosynthetically active radiation into water bodies increases with an increase in transparency and solar altitude. The quantity of solar energy penetrating to the deeper layers increases with an increase in water transparency and decreases with an increase in depth. Figures 3, tables 2; references: 8 Russian.

UDC 532.543

COMPUTATION OF DYNAMICS OF RIVER FLOWS UNDER NONSTATIONARY CONDITIONS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 20 Jan 81) pp 79-87

[Article by G. A. Raspopin, candidate of technical sciences, and Ye. A. Kovalev, Novosibirsk Civil Engineering Institute and Mathematics Institute, Siberian Department, USSR Academy of Sciences]

[Abstract] At present there is no universal method for computing nonstationary flows in rivers with wind and Coriolis force taken into account and thus there is no satisfactory method for determining local velocities and levels for any given moment. The authors here describe a successful algorithm for computing the dynamics of river flows in channels having time-variable discharges and wind velocities. As a theoretical basis use is made of the known equations of motion in stresses, the continuity equation and the Boussinesq hypothesis. The pressure distribution in the flow is described by the equation of hydrostatics. The fundamental equation employed in the computations is the continuity equation written in finite differences. The proposed algorithm is characterized by rapid convergence. The algorithm is illustrated in the example of computations of the dynamics of flow in the Ob' channel at Barnaul. There was an excellent agreement of computed and measured parameters with respect to the velocity vector modulus and its direction. The nature of river flow is influenced considerably by wind velocity and direction. The proposed method is shown to be universal. It takes into account all the principal factors exerting an influence on the flow, including friction at the free surface, inertial terms and Coriolis force. As a result, the vectors of bottom and surface velocities have a different direction, making it possible to describe circulation currents caused by meandering of the channel, Coriolis force and wind. The computation algorithm is simple and requires little computer time. It therefore can be recommended for wide use in the planning and construction of hydraulic structures on rivers. Figures 3; references 7; 6 Russian, 1 Western.

UDC 551.521

MODELING OF RADIATION REGIME IN PLANT COVER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 31 Mar 81) pp 88-93

[Article by O. A. Anisimov and G. V. Menzhulin, candidate of physical and mathematical sciences, State Hydrological Institute]

[Abstract] The models of the radiation regime in the plant cover which have already been published do not fully clarify the possibilities of radiation transfer theory. This is attributable primarily to the fact that in order to facilitate solution of the pertinent system of integrodifferential equations it has been necessary to introduce simplifying assumptions which considerably limit the sphere of possible application of the modeling results. In order to test fully the possibilities of radiation transfer theory the authors have developed a model of the radiation regime of a horizontally uniform plant cover without assumptions concerning its phytometric and optical properties limiting universality. The results of numerical experiments are presented. The phytometric characteristics of the plant cover (relative size of leaves, relative area of the detector registering radiation, profile of specific leaf surface and orientation of leaves) were interpreted as random functions with a priori stipulated distributions. The algorithm used in connection with the statistical tests method made it possible to compute the distribution function (probability density) for direct solar radiation at any height in the plant cover. The systematic discrepancies between the experimental data and the results of model computations are explained. A method for developing a theory of radiation transfer in a high-dispersion, two-phase medium is proposed. Figures 2; references: 3 Russian, 2 Western.

UDC 632.11:633.11(574.11)

AGROMETEOROLOGICAL CONDITIONS, CROP YIELD AND QUALITY OF SPRING WHEAT GRAIN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 6 Nov 80) pp 94-101

[Article by L. G. Pigareva, candidate of agricultural sciences, Western Kazakhstan Agricultural Institute]

[Text]

Abstract: A group classification of agroclimatic indices determining the corresponding changes in crop yield and the quality of spring wheat grain and the possibility of their prediction is substantiated. Procedures are proposed for increasing the effectiveness of use of photosynthetically active radiation by plants, governing the increase in yield and quality of grain, as well as the output of the final product -- bread.

A search for means for agricultural crops to make the most effective use of agroclimatic resources against a background of a high level of agricultural crop cultivation techniques is an important and timely problem in the effort to enhance crop yield and the quality of production. For Kazakhstan this problem is even greater because as a result of the exploitation of the virgin and idle lands it has been transformed into one of the principal regions for the production of high-quality grain from wheat of strong and hard varieties.

The sharp fluctuations in yield and the technical qualities of grain from the spring wheat varieties Saratovskaya-210, Saratovskaya-42 and Saratovskaya-40 on the dark chestnut soils of northwestern Kazakhstan during six successive years (1974 and 1975, 1976 and 1977, 1978 and 1979) is evidence that a favorable combination of solar radiation, number of hours of sunlight and moisture supply results in revelation of the potential biological possibilities of the variety and indicates ways to make effective use of agrometeorological factors for the purpose of ensuring a stable yield of wheat with a high quality of grain.

In the zone of northwestern Kazakhstan soft wheat of the Saratovskaya-42 and Saratovskaya-210 varieties can form up to 20% protein in the grain, more than 40% first-group gluten and ensure a volumetric yield of bread from 100 g of flour of 735 cm^3 with an evaluation of 5 scale units (without improvement).

In individual years these indices decrease sharply, to 11.24%, 19.20% (IDC-1 100) and 195 cm^3 respectively, which results in a low quality of the grain and reduces the bread yield. Bread, as the fundamental product of nutrition, is evaluated, on the one hand, by quality (calorie content, protein quantity, etc.), and on the other hand, by quantity, that is, the volumetric yield from 100 g of flour. The volumetric yield of bread in turn is a function of many factors:

[y = m; π = soil] $$V = f(Б_{\%}, K_{\%}, T, \Pi_{п}, A, \Sigma t_{\odot}, \Sigma ФАР, K_у),$$ [ФAR = PAR]

where V is the volumetric yield of bread; $Б_{\%}$ is the protein content of the grain; $K_{\%}$ is the gluten and its quality; T is the technology employed in bread production; Π_{soil} is soil fertility; A is the agricultural technique employed; $\Sigma t_{\odot}$ is the sum of hours of sunshine during the wheat growing season; Σ PAR is the sum of photosynthetically active radiation during this same period; K_m is the moistening coefficient,

$$K_у = \frac{\Sigma h}{0,45 \Sigma d};$$

Σh is the sum of falling precipitation; Σd is the sum of the mean daily air moisture deficits during the agricultural year.

Our experiments in 1970-1979 were carried out at the same level of agricultural techniques, on dark chestnut soils, and the technology for the production of bread from 100 g of flour remained standard. Under these conditions $\Sigma t_{\odot}$, Σ PAR and K_m were decisive in the change in the volumetric yield of bread.

Thus, the volumetric yield of bread was examined from the point of view of its dependence on the protein content of the grain, quantity and quality of the gluten, which in turn are determined by the above-mentioned integral agrometeorological indices. An analysis of available materials for the last 10 years (number of experiments n = 107) indicated that the prevailing agrometeorological conditions also determine the yield and the quality of the grain; K_w, Σ PAR and $\Sigma t_{\odot}$ have a high correlation with the latter.

Moisture under the conditions in our zone limits the process of photosynthesis of plants, but in moist years Σ PAR and $\Sigma t_{\odot}$ limit both the yield and quality of grain.

In this connection a differential analysis of the dependence of the quality of grain, yield, volumetric yield of bread on agrometeorological conditions enabled us to discriminate five groups of K_w and Σ PAR values which can be considered agroclimatic indicators of the corresponding changes in protein content, quality of gluten and volumetric yield of bread.

Changes in K_w from 0.38 to 0.55 and Σ PAR from 100.4 to $107.9 \cdot 10^7$ J/m^2, according to our experiments, which we assigned to group 1, under unirrigated conditions ensure the formation of the highest grain yield (from 24.7 to 41.3, on the average 30.8 centners/hectare), protein content (from 19.0 to 20.0%), first-group gluten with a 100% probability and a volumetric yield of bread from 100 g of flour between 510 and 735 cm^3. With agroclimatic indices in group I, which we evaluate as optimum, the correlation coefficient between the protein content and the volumetric yield of bread is 0.701. The volumetric yield of bread from 100 g of flour with a protein content of the grain 19.50% attains a maximum value 735 cm^3. It is important to note that with the indicated agrometeorological conditions the protein content in wheat grain of the varieties Saratovskaya-42 and Saratovskaya-210 attains 20% and reaches a plateau (Fig. 1).

Agroclimatic indices of group II (K_w from 0.31 to 0.38 and $\sum$ PAR from 95.0 to $100.3 \cdot 10^7$ J/m^2) result in a yield of 20.3 centners/hectare (from 14.0 to 30.0 centners/hectare) and the formation of protein content in the grain from 16.75 to 18.50%, as well as first-group gluten with a 77% probability. The volumetric yield of grain from 100 g of bread under these conditions is from 475 to 700 cm^3.

Group III takes in cases with K_w from 0.23 to 0.30 and $\sum$ PAR from 82.0 to $94.9 \cdot 10^7$ J/m^2. We evaluate these agroclimatic indices as "average." They result in a yield of 15.0 centners/hectare (from 7.0 to 25.2 centners/hectare), a decrease in the protein content to 14.0-16.0%, a quality of second-group gluten with a 48% probability and maximum variations in the volumetric yield of bread from 100 g of flour -- from 195 to 610 cm^3.

Group IV of agroclimatic indices is characterized by a relatively high moistening coefficient (from 0.30 to 0.70), but a low sum of PAR during the "sprouting-gold ripeness" period (from 66.40 to $82.00 \cdot 10^7$ J/m^2), which is a condition for the formation of grain with a yield of 24.9 centners/hectare (from 15.7 to 37.0 centners/hectare), but a low protein content (from 11.0 to 13.2%) and second-group gluten up to 75%.

A considerable reaction of plants to change in $\sum$ PAR is characteristic of the processes transpiring under the influence of indices of this group. With an increase in the $\sum$ PAR the protein content attains 13.2% and the volumetric yield of bread from 100 g of flour is 515 cm^3. We categorized agroclimatic indices of group IV as "satisfactory." In group V we included K_w below 0.20 and a high sum of PAR (from 90.0 to $100.0 \cdot 10^7$ J/m^2 or more). Such a combination of agroclimatic indices, which we designated as "unsatisfactory," in actuality has no value in production. In the case of a low moistening coefficient plants do not assimilate PAR and this does not ensure a yield even for replacing the expended seed; the grain in such cases will usually be incompletely filled and impoverished, although its protein content can attain 17%.

The principal groups of agroclimatic indices, determining the change in protein content of grain of spring wheat of the variety Saratovskaya-42 with different combinations of the moistening coefficient and PAR sum, are represented in the form of a three-dimensional diagram (Fig. 2). On this diagram K_w is read along the right side of the base of the parallelpiped, the sum of PAR during the "sprouting-total maturity" period is plotted along the left edge, and the protein content of the grain is read along the vertical edge.

The diagram, constructed on the basis of actual data, gives a graphic idea concerning the dependence of protein content in the grain on K_w and $\sum$ PAR. Thus, the maximum protein content of spring wheat grain of the variety Saratovskaya-42 was obtained with a moistening coefficient 0.50-0.60 and a sum of PAR $105 \cdot 10^7$ J/m^2. With this same moistening coefficient but a sum of PAR $60 \cdot 10^7$ J/m^2 the protein content is reduced to 11.50-12.00%, but with a moistening coefficient 0.70 or above the protein content falls even to 11.24%.

In northwestern Kazakhstan both a decrease (from 0.50) and an increase (from 0.60) in the moistening coefficient, on the one hand, and a decrease in the sum of PAR, on the other, cause a decrease in the quality of grain and especially one of its principal indices -- protein content.

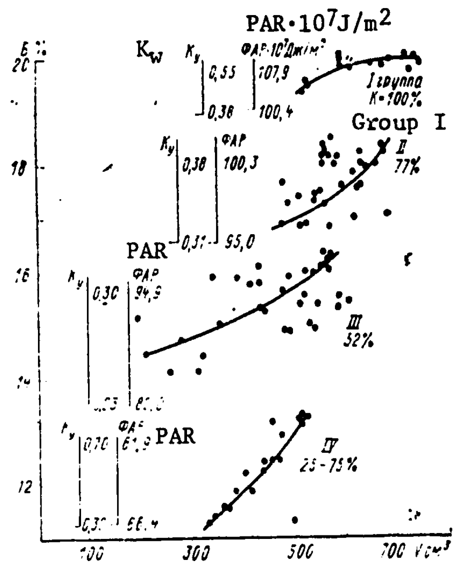

Fig. 1. Principal groups of agroclimatic indices determining quality of grain and volumetric yield of bread (V) from 100 g of flour from spring wheat of variety Saratovskaya-42. Б % -- protein content of grain; K% -- gluten, IDC-1 ⩾ 50-70, PAR -- during period "sprouting-total maturity"; K_w -- moistening coefficient

During moist 1976 and 1978, with irrigation during the period of the initial stages of grain formation, the grain was puny and there was a reduction to 25% of the yield, which was caused, in our opinion, by "runoff" of the grain.

In northwestern Kazakhstan and in the regions adjacent to it the deficit of precipitation in more than 70% of the years reduces the effectiveness of use of light and heat resources by the wheat plants. The classification of the groups of agroclimatic indices determining the yield and quality of the grain served as a basis for seeking methods and procedures for the optimum (under the given conditions) spatial-temporal moisture supply and the maximum utilization of solar radiation by plants.

The reserves of productive moisture in the soil layer 0-100 cm at the beginning of the sowing season constitute an agrometeorological index which to a considerable degree determines the fate of the future yield. However, with one and the same moisture reserves in the soil for the rational use of agroclimatic resources both in the initial and in the subsequent phases of development of plants it is extremely important to determine (with allowance for agroclimatic conditions) the optimum times of sowing and to ensure the sowing of spring wheat at these times.

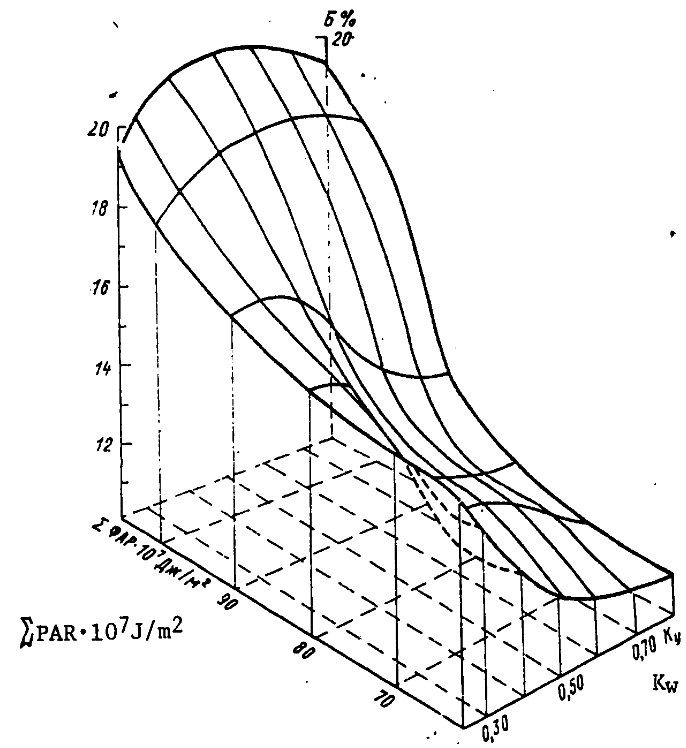

Fig. 2. Change in protein content of wheat grain of Saratovskaya-42 variety with different combinations of moistening coefficient and PAR.

In the case of early sowing times a shortage of heat inhibits the appearance of early sprouts, whereas weeds actively absorb the moisture reserves and develop rapidly. Early sowings most frequently are spare, develop lesser leaf surface, fall under the influence of May droughts and searing winds and develop prematurely. As a result, the plants receive a lesser sum of photosynthetically active radiation.

In the case of late sowing times and moisture reserves in the soil of not less than 50% of the total field moisture capacity the duration of the "sowing-sprouting" phase does not differ from its duration with optimum sowing times, but the duration of the subsequent development phases is sharply reduced. The reasons for this are the high temperatures and the deficit of air moisture, as well as high transpiration. At the midday hours the plants lose their state of turgor, have a weak increase in leaf surface, which in the last analysis results in a reduction in yield and quality of grain.

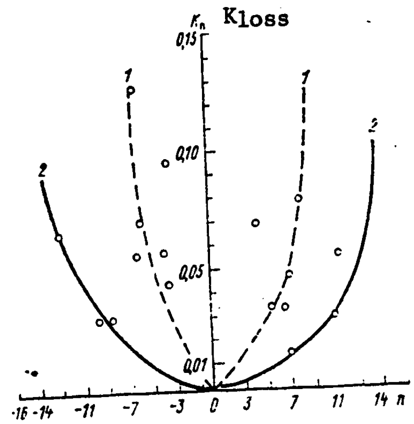

Fig. 3. Dependence of loss of yield ($K_{loss} = \frac{Y_0 - Y_n}{Y_0 n} \frac{\text{part}}{\text{day}}$) of spring wheat on sowing time. 1) Saratovskaya-40; 2) Saratovskaya-42; o -- optimum sowing date; n -- number of days from optimum date; K_{loss} -- coefficient of yield loss; Y_0 -- yield with sowing on optimum date; Y_n -- yield with deviation by corresponding number of days from optimum date.

Thus, unfavorable conditions develop with both early and late sowing times. Even with satisfactory moisture reserves (70% of soil moisture capacity) the deviation of sowing times from the optimum dates causes a sharp reduction in the yield, especially for valuable varieties of spring wheat. Our investigations, carried out in 1970-1979, indicated that even a small deviation from the optimum sowing date in the direction of both early and later times results in considerable yield losses and with a deviation by 7 days these losses attain 7.8 centners/hectare. A graphic idea concerning this is given by the curves of losses in the yield of wheat of the hard varieties Melyanopus-26, Saratovskaya-40 and the soft varieties Saratovskaya-210, Saratovskaya-42 (Fig. 3). It should be noted that the losses of yield of hard wheat with a deviation from the optimum sowing date by one and the same number of days exceed the losses of yield of soft wheat. This means that hard wheat is more demanding on agrometeorological conditions and in favorable years (1974, 1976) its yield is higher than the yield of soft wheat.

On the other hand, with nonadherence to optimum sowing times, especially during arid years, the yield of hard wheat decreases sharply.

In order to determine the optimum sowing dates we will employ the method of temperature-phenological nomograms, which is based on an allowance, on the one hand, for the dynamics of the mean 10-day air temperatures on the basis of long-term data and each specific year, and on the other hand, the biological requirements of spring wheat to a change in mean daily temperatures and moisture supplies by phases of development.

Table 1

Sowing Times, Crop Yield, Grain Quality and Agrometeorological Indices for the Growing Season of Spring Wheat, Saratovskaya-42. Sovkhoz imeni Frunze. In Ural'skaya Oblast, Northwestern Kazakhstan

Index	Phase	21 IV early	27 IV optimum	10 V late	1 V early	14 V optimum	19 V late
		1978 г. K =0,55			1979 г. K =0,33		
1) Число дней, Σn	9) «посев — всходы»	12	7	7	11	7	7
	10) «всходы — полная спелость»	82	87	80	73	83	74
2) Сумма часов солнечного сияния, $\Sigma t_{\odot}$	10) «всходы — полная спелость»	747	813	689	750	790	673
3) Σ ФАР$\cdot 10^7$ Дж/м^2	10) «всходы — полная спелость»	97,4	103,3	95,0	86,8	98,7	88,0
4) Урожайность, ц/га		26,0	29,2	21,8	6,8	18,7	17,8
5) Белок, %		17,64	19,17	17,52	15,12	15,83	14,44
6) Клейковина, %/ИДК-1		32,9/70	35,9/70	32,4/50	34,0/90	32,0/85	28,0/55
7) Объемный выход хлеба из 100 г муки, см^3		480	635	540	105	340	210
8) Группы агроклиматических показателей		II	I	II	III	II	III

KEY:

1. Number of days, $\sum n$
2. Sum of sunshine hours, $\sum t_{\odot}$
3. $\sum$ PAR$\cdot 10^7$ J/m^2
4. Yield, centners, hectare
5. Protein, %
6. Gluten. %/IDC-1
7. Volumetric yield of bread from 100 g of flour, cm^3
8. Groups of agroclimatic indices
9. "Sowing-sprouting"
10. "Sprouting-total maturity"

An analysis of the yield of regionalized varieties of spring wheat which we used, Saratovskaya-42 and Saratovskaya-40 in experiments and production fields, indicated that the shortest "sowing-sprouting" period (6-7 days) under the conditions of the very continental climate of northwestern Kazakhstan corresponds to a stable mean daily air temperature of 14-15°C, which also determines the optimum sowing date. With this air temperature and reserves of productive moisture not less than 50% of the field moisture capacity in the soil layer 0-100 cm relatively favorable conditions are created for the early phases of development of spring wheat. According to long-term data, for the northern regions of the zone and the experimental field of the West Kazakhstan Agricultural Institute the optimum sowing date falls in mid-May; for the southern regions -- in the middle of the first 10-day period of May. During specific years, depending on the value of the meteorological elements, the optimum date of sowing varies in the range from the beginning of the second 10-day period in April to the end of the second 10-day period in May.

Table 2

Dependence of Yield and Quality of Spring Wheat Grain on Orientation of the Sown Rows. Sovkhoz imeni Frunze, Ural'skaya Oblast, Northwestern Kazakhstan

Years	Direction of sowing	Yield, centners/hectare	Protein, %	Gluten, %	Protein yield kg/hectare
		Saratovskaya-42			
1975	N-S	5,3	18,13	38,2	96
	E-W	4,0	17,24	34,5	69
1976	N-S	22,8	16,00	34,8	365
	E-W	21,3	14,88	31,6	317
1977	N-S	8,0	17,98	33,8	144
	E-W	7,0	17,64	32,2	123
1978	N-S	30,4	19,97	37,5	607
	E-W	27,9	16,84	30,1	470
Mean	N-S	16,6	18,02	36,1	303
	E-W	15,0	16,65	32,1	244
	Increment	1,6	1,37	4,0	59
		Saratovskaya-40			
1975	N-S	3,5	19,19	42,4	67
	E-W	2,0	18,84	35,2	38
1976	N-S	24,6	14,58	25,6	359
	E-W	21,9	13,58	26,1	297
1977	N-S	6,7	17,64	32,8	112
	E-W	5,0	16,72	30,4	84
1978	N-S	30,3	19,19	34,0	603
	E-W	25,5	18,09	32,0	461
Mean	N-S	16,3	17,65	33,7	285
	E-W	13,6	16,81	30,9	220
	Increment	2,7	0,84	2,8	65

We feel that the last two years (1978 and 1979) warrant special attention. In 1978, according to the forecast, during the third 10-day period of April, the air temperature was to be 3°C above the mean. Therefore, according to our computations, the optimum sowing date was expected on 27 April (experimental field at the Agricultural Institute, Sovkhoz imeni Frunze, Ural'skaya Oblast). In 1979 during the first 10-day period in May the temperature was close to the mean long-term value and the optimum date for sowing was 14 May. In the field experiments the earliest date for sowing was determined by the possibility of operation of the drill. Sowing at late times was carried out three or four times each subsequent three days from the optimum date.

An analysis of the collected data (Table 1) reveals that the optimum sowing date results in a minimum duration of the "sowing-sprouting" phase (7 days) and a maximum duration of the "sprouting-gold ripeness" phase during the season (in 1978 -- 87 days; in 1979 -- 83 days). Such a duration of the development phases predetermines a high sum of sunshine hours (813 and 790), sum of PAR (103.3 and 98.7$\cdot 10^7$ J/m^2), and as a result -- a higher yield (29.2 and 18.8 centners/hectare) and better technological indices of the grain. With early and late sowing times the duration of the "sprouting-gold ripeness" period is reduced by 5 or more days, as a result of which the plants receive a lesser sum of sunshine hours and sum of PAR ensuring the photosynthesis process. The yield and quality of the grain in this case are reduced to the level governed by the agroclimatic indices of groups II and III.

At the present time in the programming of yields of agricultural crops more and more attention is being devoted to photosynthetically active radiation [1, 3-5], since the more the quantity of solar energy which plants can assimilate, the greater will be their yield. This, as indicated by our investigations, is favored, on the one hand, by optimum sowing times, and on the other hand, by a north-south orientation of the sown rows.

In the case of a N-S orientation of the rows, in comparison with W-E, all other conditions being equal (moisture supply, agricultural techniques, etc.) the plants in our experiments received a sum of PAR during the growing season which was 18.7$\cdot 10^7$ J/m^2 greater, and this in turn ensures a better developed leaf surface and root system, higher indices of elements of yield structure, an increase in the yield and technological qualities of the grain. Table 2 gives the results of our four years of experimentation (1975-1978) carried out in an experimental field at the West Kazakhstan Agricultural Institute with soft and hard wheats. The table shows that the mean increment of yield, protein, gluten and protein yield from one hectare of wheat of the Saratovskaya-42 variety were 1.6 centner/hectare, 1.37%, 4.0% and 59 kg/hectare respectively, and for the variety Saratovskaya-40 -- 2.7 centners/hectare, 0.84%, 2.8% and 65 kg/hectare.

The agrometeorological validation of the optimum sowing times for spring wheat, its sowing in rows primarily of a N-S orientation, are procedures ensuring the plants the best agrometeorological conditions and as a result of this give a considerable economic effect. This is indicated by data from field tests carried out at a number of farms in northwestern Kazakhstan. The use of these procedures at the Sovkhoz imeni Frunze in Zelenovskiy Rayon in Ural'skaya Oblast during 1975-1979 ensured a mean five-year yield increment of 2.7 centners/hectare, as a result of which the sovkhoz without the slightest additional expenditures received an additional 26,173 centners of high-quality grain of strong wheat, and converted to money this is 265,978 rubles. In 1979, with relatively unfavorable weather conditions, on only four farms in the oblast -- the "Frunze" and "Kushumskiy" sovkhozes in Zelenovskiy Rayon, at the "Tel'man" kolkhoz in Burlinskiy Rayon and at the "Kuybyshev" sovkhoz in Chapayevskiy Rayon, as a result of the use of these procedures the mean increment in yield was 1.7 centner/hectare and the farms without the slightest additional expenditures received 9,210 centners of spring wheat of the Saratovskaya-42 variety or more than 81,367 rubles of additional income.

In this connection we feel that it is necessary to introduce the mentioned simple, but rather effective agrometeorological recommendations into agricultural production more extensively and with greater vigor and thereby make a significant contribution to increasing the production of grain and an increase in its technological qualities.

BIBLIOGRAPHY

1. Nichiporovich, A. A., "Ways to Increase the Productivity of Photosynthesis of Plants in Sown Fields," FOTOSINTEZ I VOPROSY PRODUKTIVNOSTI RASTENIY (Photosynthesis and Problems in Plant Productivity), Moscow, Izd-vo AN SSSR, 1963.

2. PSHENITSY MIRA (World Wheats), edited by D. D. Brezhnev, compiled by V. F. Dorofeyev, Leningrad, Kolos, 1976.

3. Timiryazev, K. A., "Plants and Solar Energy," SOLNTSE, ZHIZN', KHLOROFILL (Sun, Life and Chlorophyll), Moscow, Sel'khozgiz, 1956.

4. Tooming, Kh. G., SOLNECHNAYA RADIATSIYA I FORMIROVANIYE UROZHAYA (Solar Radiation and Yield Formation), Leningrad, Gidrometeoizdat, 1977.

5. Shul'gin, I. A., SOLNECHNAYA RADIATSIYA I RASTENIYE (Solar Radiation and Plants), Leningrad, Gidrometeoizdat, 1967.

UDC 551.509.313

DISCRIMINATION OF TRAVELLING WAVES FROM EXPERIMENTAL DATA

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 29 Dec 80) pp 102-104

[Article by A. A. Krivolutskiy, Central Aerological Observatory]

[Abstract] Global waves propagating along a circle of latitude, associated with the gyroscopic stability of the atmosphere (Rossby waves), are of great interest to meteorologists. It is important to be able to determine the structure of such travelling waves and separate standing and travelling waves of the same period. R. J. Deland (J. METEOROL. SOC. JAPAN, Vol 50, 1972), for example, represented a disturbance in the form of sums of waves of the same period travelling toward one another (with summation for all periods). But that intuitive form of representation did not take into account the possible influence of standing waves. This made it necessary for others to correct the method, which greatly complicated the procedure for discriminating the travelling wave. Thefore, the author has proposed a method which makes determination of the amplitudes of travelling and standing waves quite simple. Assuming that $Y(t, \lambda)$ is the distribution of a meteorological parameter at some level as a function of time t and longitude λ, and representing $Y(t, \lambda)$ in the form of an expansion in a two-dimensional Fourier series, a series of expressions is derived for representing the real field in the form of a series, thereby obtaining the amplitudes of the waves for discrete values of frequencies (periods). Formulas are then derived for separate determination of the time spectra of travelling and standing waves for any s, whose value characterizes the contribution of variations with a different longitudinal structure to the total variability. The described procedure was applied to analysis of real data: daily geopotential data for the circle of latitude 60°N at the level 100 mb for the winter of 1972/1973. During this period one-dimensional statistical analysis reveals variations with a period of 27-28 days in the zonal circulation index series. An effort was made to ascertain whether these variations were associated with a propagating planetary wave. The length of the interval was about five months. It was found that variations with a period of 27-28 days cause a planetary wave with a longitudinal wave number s = 1. There were virtually no travelling waves with other s. For s = 2 there was a standing wave with a period close to 40 days. Figures 1; references 9: 2 Russian, 7 Western.

UDC 551.513

INVESTIGATING THE CONVERGENCE OF A DRY CONVECTIVE ADAPTATION SCHEME IN MODELS OF MACROSCALE ATMOSPHERIC PROCESSES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 11 Dec 80) pp 105-107

[Article by I. V. Cholakh, West Siberian Scientific Research Institute]

[Abstract] In models of general circulation of the atmosphere it is now common to use a scheme for dry convective adaptation which was proposed by S. Manabe, et al. In the review of this scheme it is pointed out that as a result of such adaptation there can be a disruption of stability of stratification of adjacent layers and then the entire procedure must be repeated. In the models a limit is sometimes set on the number of such iterations since the matter of the finiteness of the iteration process or its convergence has not been studied. This question is examined here in a special case. It is assumed that the number of levels is 3 and it is further assumed that the initial distribution of temperatures is such that only the lower layer requires adaptation and after its adaptation there is disruption of stratification of the upper layer. It is shown that the process of convective adaptation will continue infinitely. Accordingly, a modified procedure is proposed and it is shown under what conditions the convective adaptation procedure will continue a finite number of steps. This improvement in the scheme is completely applicable to a case when it is assumed that the convective adaptation is accomplished layer-by-layer, that is, when at each moment the temperature values are scaled only at two adjacent levels. References: 2 Russian.

UDC 551.509.313

DETERMINING PARAMETERS OF CORRELATION FUNCTIONS DURING OBJECTIVE ANALYSIS OF HYDROMETEOROLOGICAL FIELDS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 28 Nov 80) pp 108-110

[Article by B. Bakirbayev and V. V. Kostyukov, candidate of physical and mathematical sciences, West Siberian Scientific Research Institute and Computation Center, Siberian Department, USSR Academy of Sciences]

[Abstract] Optimum interpolation is an effective means for describing and studying hydrometeorological fields. However, its use is possible only with the availability of statistical information on the elements to be analyzed, usually as a result of processing of a great number of measurements. Therefore, for elements in which interest has recently arisen, and accordingly, whose statistical structure has been studied poorly, no interpretation can be made by the mentioned method. The authors have therefore proposed a generalization of optimum interpolation making it possible to carry out objective analysis in the absence of precise data on the correlation function. It is only necessary to assume its general character, expressed by a functional dependence on distance. The specific form is determined in the course of the analysis. The essence of the approach is that the minimum of the mean statistical error is sought using not only the values of the interpolation weights, but also the unknown parameters of the correlation function. Station measurement data are used as superposed correlations, which makes it possible to ascertain the sought-for values of the parameters. The method evidently can be used in cases of complete absence of statistical information on the analyzed element, for example, for the fields of contaminations by different ingredients, which may even have a unique character. The application of the method is illustrated for the geopotential field AT_{500}, surface temperature of the Black Sea and the concentration of radioactive contamination of Atlantic waters by ^{90}Sr. Tables 1; references: 5 Russian.

UDC 551.575.551.576.11.551.465.7

FORMATION OF STRATUS CLOUDS AND FOGS ON HYDROLOGICAL FRONTS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 17 Nov 80) pp 110-112

[Article by V. V. Rossov, candidate of geographical sciences, Polar Scientific Research Institute of Marine Fishing and Oceanography]

[Abstract] During recent years satellite information has come into use for determining the position of hydrological fronts in the oceans. In addition to infrared sensing methods, it is also possible to use remote determination of the position of hydrological fronts on the basis of cloud cover on images in the visible spectral range. It is assumed that if in a low-gradient pressure field over the ocean an air mass moves in the direction of cold waters, the boundary of the stratus clouds or fog coincides with the position of the hydrological front, whereas with the movement of the air mass in the direction of the warm waters a cumulus cloud cover is formed over the warm waters. The author has endeavored to clarify (semiempirically) at what distance from the front and under what temperature contrast conditions on the front there can be formation of stratus clouds or fog. The analysis reveals that in the first approximation it can be assumed that under conditions typical for the ocean $r_0 > 80\%$ and small $T_0 - T_1$ values (r_0 is relative humidity, $T_0 - T_1$ is the difference between the air temperature in the near-water friction layer and the surface temperature of the underlying water mass) the dew point is attained at a relatively short distance from the front over cold water, but with a high $T_0 - T_1$ value and a broad transition (frontal) zone a fog or stratus clouds can also develop over the frontal zone itself. (The width of the transition zone for mean conditions is reckoned at about 25 km.) A table gives the results for different variables: $T_0 - T_1 = 5, 10, 15^\circ$ and $r_0 = 50, 60, 70, 80, 90\%$. Figures 2, tables 1; references: 5 Russian.

UDC 551.465.7:629.78

ROLE OF ADVANCED SPACE SYSTEMS IN IMPLEMENTING THE OCEANOGRAPHIC PART OF THE WORLD CLIMATE RESEARCH PROGRAM

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 (manuscript received 31 Mar 81) pp 113-119

[Article by I. F. Berestovskiy and S. V. Viktorov, candidate of physical and mathematical sciences, USSR State Committee on Hydrometeorology and Environmental Monitoring and Leningrad Division, State Oceanographic Institute]

[Text]

Abstract: In this review, based on materials of the International Coordination Conference, the authors examine the problems related to the use of space information in the implementation of major oceanographic experiments planned within the framework of the World Climate Research Program in the late 1980's. Plans and programs for the creation of satellites and space systems of interest for oceanography are set forth.

1. Introduction. A conference on the coordination of plans for future satellite systems for sensing the earth and oceanic experiments organized within the framework of the World Climate Research Program was held during the period 26-31 January 1981 near Oxford (England) under the aegis of the World Meteorological Organization (WMO), International Council of Scientific Unions (ICSU) and the Intergovernmental Oceanographic Commission of UNESCO. This conference was called by the Joint WMO/ICSU Scientific Committee on the World Climate Research Program and the Program for Investigation of Global Atmospheric Processes and the SCORE/IOC Committee on Changes in Climate and the Ocean.

The conference was attended by scientists from 12 countries, including specialists of the USSR State Committee on Hydrometeorology and Environmental Monitoring.

The tasks of the conference were as follows:
-- discussion of the problem of what type of space system for remote sensing of the ocean is the most acceptable for use in the implementation of major oceanographic experiments planned within the framework of the World Climate Research Program in the late 1980's;
-- analysis of existing plans for the launching of satellites, data from which can be used for oceanographic research;

-- formulation of recommendations for optimizing these plans for the purpose of achieving the maximum effect when using advanced oceanographic space systems within the framework of the World Climate Research Program.

The conferees were familiarized with the Preliminary Plan of the World Climate Research Program (WCRP) and with the existing plans for the organization of major international oceanographic experiments within the framework of the WCRP. The representatives of the USSR, United States, Japan and the European Space Research Agency told the conferees about the preliminary plans for creating satellites and space systems which are of interest for oceanography. Also examined were the problems involved in the development of new methods and apparatus (including satellite equipment) necessary for implementing the oceanographic part of the WCRP and the problems relating to the rational joint use of space and traditional methods for obtaining oceanographic data.

2. World Climate Research Program (WCRP)

The principal purpose of the WCRP is a determination of the degree of predictability of climate and the influence of mankind on climate. In order to achieve this goal it is necessary to solve the following problems:

-- improve our knowledge concerning global and regional climate, variations of climate and the mechanisms responsible for these variations;
-- determine the presence of significant trends in global and regional climate;
-- develop and improve physical and mathematical models capable of describing and predicting climatic phenomena of different spatial and temporal scales;
-- study of the response of climate to possible natural and anthropogenic influences and evaluation of climatic changes as a result of such modification.

The principal WCRP time scale is from several weeks to several decades. However, this also includes processes of a synoptic scale. The spatial scale is from regional (about 1000 km) to global, the emphasis being on the desirability of developing methods making it possible to interpret macroscale results within the framework of local phenomena.

In the Preliminary Plan for the WCRP the terms weather, climate and climatic changes are defined and components of the climatic system are determined. This system includes the atmosphere (including the troposphere and stratosphere), oceans, cryosphere (including the ice and snow of the oceans and continents, land and also the biosphere. Although there are no elements in the program which can be neglected, from among the many climatologically important processes it is possible to discriminate two which require special attention. This is attributable both to their special position as the factors determining the climate and to the fact that in order to organize experimental programs for their study it is necessary to invest a great amount of time. These processes include the process determining the influence of cloud cover on the radiation energy balance of the climate system and the process determining the influence of physics and dynamics of the ocean on the global circulation of heat, water and chemical substances (especially carbon) in the climate system.

The WCRP provides for extensive theoretical and experimental studies for investigating oceanic processes. In the section "Oceanic Processes" of the Preliminary Plan for the WCRP it is emphasized that in comparison with the atmosphere the system for observing and modeling the ocean is developed to a considerably lesser degree. Accordingly, the purpose of the oceanographic part of the WCRP should be an improvement in our comprehension of the three-dimensional circulation of heat, water and chemical substances (especially carbon) in the world ocean, and thus a clarification of the role of oceanic processes in the climate system. Particular attention should be devoted to the factors which can exert an influence on changes in atmospheric climate at the principal WCRP time scales.

In the Preliminary Plan for the WCRP it is pointed out that the collection of quite representative data concerning the world ocean is a grandiose problem which simply cannot be accomplished without using new methods. It requires a changeover from an almost complete reliance on scientific ships to a new era in the use of instrumentation carried aboard regular ships, drifting and anchored buoys, on the sea floor and satellites. This process has already begun and should be accelerated for the successful implementation of the WCRP.

3. Major International Oceanographic Experiments Planned for the End of the 1980's Within the Framework of the World Climate Research Program

It is noted that existing international and national programs for study of the ocean will not be able to satisfy all WCRP requirements. Therefore, the Preliminary Plan for the WCRP provides for carrying out special oceanographic projects for ensuring receipt of the most representative information.

a) An experiment for studying global circulation of the ocean. The purpose of this experiment is a considerable decrease in the presently existing uncertainty of our knowledge concerning macroscale oceanic circulation, including seasonal variations of circulation in the upper layer of the ocean (at least to a depth of 1 km). It is assumed that this objective can be attained with the joint use of diagnostic models based on the geophysical "inverse" method and observations made using different new technical apparatus. The experiment, which is to be carried out in the late 1980's, will create an information base for the development of climatic models of interaction between the ocean and the atmosphere.

The principal role in this experiment is to be played by satellite systems for measuring the level surface of the ocean. Professor C. Wunsch visualizes that by the late 1980's, beginning in approximately 1986, there will be an altimetric satellite with a lifetime of several years in the necessary orbit (or more than one such satellite), with a small orbital inclination; there will be an altimetric satellite with a solar-synchronous orbit and also a gravitational satellite.

The following requirements are being placed on the characteristics of apparatus for an altimetric satellite. It should ensure measurement of the distance from a satellite to the sea surface with an accuracy attaining two centimeters. The measurement system must determine the level surface of the ocean relative to the terrestrial ellipsoid with an accuracy to 10 cm in segments of about 3000 km or shorter and the accuracy should attain 4 cm in horizontal 30-km segments. The orbital inclination will be about 65° with repetition of transit of the subsatellite line through any point with an accuracy of ±1 km each 10 days. The minimum lifetime of the satellite will be 5 years.

Efforts must be undertaken for improving our knowledge concerning the sea geoid, especially at scales from several hundreds to several thousands of kilometers. The principal role in such work will evidently be played by a special gravitational satellite. It is supposed th · it should be launched prior to ending of the five-year lifetime of the altimetric satellite. Using the data obtained from the gravitational satellite it should be possible to decrease the systematic errors in measurements by the altimetric satellite to the level 4 cm or less for any revolution. Then in segments of about 500 km or more the ocean level surface will be determined with spatial averaging with an accuracy to less than 1 cm. Thus, it is expected that general circulation and its variability (from mesoscale to interannual) will be determined with an accuracy to several centimeters per second, at least for most of the earth's oceans.

Another important part of the planned experiment for the study of global circulation of the ocean is hydrographic investigations of the oceans in their entire depth. These will be investigations resembling those which were carried out under the program of the International Geophysical Year, but will be more extensive, with use of new methods for the collection and processing of data. The expenditure of shipboard time is estimated at eight ship-years during the entire five-year period. Altimetric measurements, in combination with improved evaluations of the geoid, will make it possible to localize the position of surface geostrophic currents in the ocean in regions of several hundred kilometers or more. Such a localization will mean that the hydrographic profiles for the first time can be used in such a way that they finally will not require the introduction of velocities of the relative level. For the first time oceanographers will be able to calculate the absolute geostrophic currents without having recourse to arbitrary assumptions concerning the levels of a "zero current" and avoid the relatively poor spatial resolution resulting from the use of inverse and relative methods.

Thus, the described concept of a global experiment assumes the collection of satellite and traditional data making it possible to determine the general circulation of the ocean, its annual and year-to-year variability with an accuracy which eliminates the existing uncertainties concerning the transfer of heat, salt and other tracers.

b) Experiment for investigation of heat flow and water masses. The objective of this experiment is to decrease the uncertainty in modern estimates of the velocities of heat and water transfer in the world ocean. The main task is to compare the different estimates applicable to a region with a large heat flow and (or) flow of water masses. According to the preliminary plan, presented by Doctor F. Dobson, for carrying out the experiment the subtropical region of the North Atlantic was selected; this area has additional advantages from the point of view of work organization and data interpretation. The mean heat flow transported in this region in a northerly direction is estimated at 10^{15}W at 24°N. Estimates of the flow differ by almost a factor of 2, but the evaluations of the errors are still greater. Within the framework of the experiment plans call for measuring the flow with a total accuracy of about ±20%. The data obtained in the course of the experiment should make it possible to determine the seasonal variability of the flow. It is supposed that the experiment will begin in the late 1980's and will continue for several years. The code name of this experiment "Kletka" (Cage) reflects the fact that with use of the difference method for estimating the velocities of transfer in the ocean it is necessary to employ a "cell" of meteorological observations in order to determine the divergence of the flow of heat and water into the atmosphere.

An important role of satellite systems in this experiment is the supplying of regular measurements of temperature of the sea surface with the maximum accuracies attainable in the late 1980's. The desirable accuracy is $\pm 0.5°K$. (Model investigations show that a temperature change of 1°K changes the quantity of the heat transfer between the ocean and the atmosphere in the middle latitudes over the area of the Atlantic Ocean by 20 W/m^2 and in the tropics by 40 W/m^2.) We note that the radiation balance over the entire zone of the experiment should be determined with an accuracy not less than ± 10 W/m^2. Using satellites plans also call for determining the characteristics of the wind over the water for the entire zone of the experiment with an accuracy to $\pm 10°$ and ± 1 m/sec. The spatial averaging for all these measurements was not more than 120 km, the frequency being once in two days.

In addition, the desire has been expressed that a study be made of the problem of the possibility of satellite measurements of the vertical profiles in the atmosphere (the accuracy in determining temperature is $\pm 1°K$, the accuracy in determining wind velocity is ± 2 m/sec, the accuracy in determining humidity is $\pm 30\%$) along the boundaries of the experimental zone.

c) Time series of oceanographic measurements. The purpose of the program "Time Series of Oceanographic Measurements" is the coordination of the activity of a number of countries for obtaining time series of oceanographic measurements in key regions. The need for studying the processes of interaction between the ocean and the atmosphere in energy-active zones of the ocean follows from the theoretical studies of Academician G. I. Marchuk. In the opinion of most scientists, the data obtained under the "Profiles" program will play an important role in comprehending a number of problems relating to interaction between the ocean and the atmosphere, and accordingly, in the development of new, more perfect models of climate and methods for long-range weather forecasts.

The approach involving the coordination of individual national and departmental experiments for the purpose of studying temporal variations in parameters of state of the ocean has received universal support; now specific plans are being developed determining the recommended profiles and the necessary observation programs.

4. Plans for Creation of Satellites and Space Systems of Interest for Oceanography

European Space Agency Program

Within the framework of the European program for remote sensing of the earth the ESA during the period 1980-1990 plans to create two types of satellite. The first (it is possible that there will be two) is intended for observation of the oceans, the second -- for investigation of the land. The program for the ERS-1 oceanographic satellite provides for solution of the following tasks:
-- the development of economic practical investigations in connection with the problems arising due to the introduction of a 250-mile economic zone;

-- improvement in understanding of dynamic processes in the ocean and in the coastal zones;
-- observation of the polar regions;
-- ensuring a considerable contribution to the WCRP.

At the present time the makeup of the on-board measurement complex has not yet been finally determined. Among the possible instruments are the following: 1) scanning microwave radiometer; 2) scatterometer; 3) side-view radar; 4) altimeter with an additional system for the precise determination of satellite position at individual points in orbit; 5) instrument for determining the color characteristics of the sea; 6) instrumentation for obtaining images of the surface in the visible and near-IR ranges.

Such an instrument complex makes it possible to determine the characteristics of the wind near the water (direction and velocity), waves (length and direction of gravitational waves, wave height, direction of internal waves), ice, topography of the ocean surface, temperature of the ocean surface, and detect zones of increased concentrations of suspended particles of different origin. There are several variants for the combining of this apparatus. For example, there is a variant of an oceanographic satellite for global observation of the ocean consisting of a scatterometer, altimeter, microwave radiometer with spatial resolution of tens of kilometers and instrumentation for obtaining images with a resolution of several kilometers with a small number of measurement channels and also a variant of an oceanographic satellite for investigating the shore zone of the ocean consisting of a side-view radar, microwave radiometer and instrumentation for obtaining images with a resolution of about hundreds of meters with narrow spectral channels. In general, with the selected orbit (solar-synchronous circular, altitude 675 km, local time of transit of satellite for 45°N -- 1130 hours) the width of the scanning zone for the on-board instrumentation (other than the side-view radar) was determined in such a way as to ensure a global coverage in 3 days.

USSR Program

System of "Meteor-2" Improved Operational Meteorological Satellites. Satellites in this series are put into a polar orbit with an altitude of about 900 km with an inclination of 81° and a period of revolution of 102 minutes. Information on the operational purpose and makeup of the on-board measurement complex has been repeatedly published. The characteristics of the "Meteor-2" meteorological system during 1981-1990 will be improved, which will make it possible to increase the effectiveness of the collected data.

"Meteor" Experimental Meteorological Satellites. The "Meteor" experimental meteorological satellites have the following purpose:
-- taking of multizonal photographs of cloud cover and the underlying surface over limited regions;
-- collection of data on the spatial distribution of zones of precipitation and their intensity, on the total liquid-water content of clouds, position of boundaries of the ice cover and their continuity;
-- collection of data on the total moisture content of the atmosphere;
-- collection of data on temperature of the underlying surface;

-- measurement of reflected radiation and its polarization components for the purpose of determining the phase composition of clouds;
-- measurement of the intensity of fluxes of corpuscular radiation.

The "Meteor-18" and "Meteor-25" were put into an orbit with an altitude of 900 km and an inclination of 81°; the "Meteor-28" and subsequent "Meteor" experimental artificial earth satellites were put into solar-synchronous orbits with an altitude of 600 km.

The sensors included:
-- scanning four-channel apparatus of the television type. Spectral intervals: 0.5-0.6 μm; 0.6-0.7 μm; 0.7-0.8 μm; 0.8-1.1 μm. Coverage on the surface of 1800 km with a resolution of 600 m at the nadir;
-- scanning two-channel apparatus of the television type. Spectral intervals: 0.5-0.7 μm and 0.7-1.1 μm. Coverage on the ground 1200 km, resolution 250 m at the nadir;
-- microwave radiometers;
-- four-channel spectrometer for measuring the intensity of fluxes of corpuscular radiation;
-- scanning IR radiometer for slant sounding for measuring thermal radiation of the upper atmosphere.

Individual "Meteor" experimental artificial earth satellites are used in direct transmissions of images obtained in the visible spectral range in one of the spectral intervals. Five satellites of this series have now been launched. The program will be continued.

Geostationary Operational Meteorological Satellites. A Soviet geostationary meteorological satellite will be launched into a geostationary orbit at an altitude of about 36 000 km and will be situated over a point about 70°E. The operational purpose will be:
-- collection of data on the distribution of cloud cover in the equatorial and temperate latitudes on the illuminated and shaded sides of the earth;
-- collection of data on the wind direction and velocity at two or three levels;
-- collection of data from surface platforms (buoys), including international;
-- dissemination of images of the cloud cover, diagnostic and prognostic weather maps on a regional and international basis;
-- collection of data on temperature of the sea surface.

The sensors will include:
-- scanning apparatus of the television type (visible part of spectrum), resolution 2-4 km;
-- scanning IR apparatus (in transparency window 8-12 μm), resolution about 12 km;
-- receiving-transmitting apparatus.

The system for the collection of data and the system for direct transmissions are planned taking into account the recommendations of the coordination conference on geostationary meteorological satellites.

Space System for Investigating the Earth's Natural Resources. In the USSR plans call for the creation of a permanently operating space system for investigating natural resources based on the use of space vehicles outfitted with instrumentation for remote measurements of parameters of the land, ocean and atmosphere.

As the principal instruments for study of the earth's surface and ocean plans call for the use of multizonal optical-mechanical scanning units with a high and intermediate resolution with the following characteristics:
-- the extent of a resolution element on the ground is 50 m in the visible range, 200 m in the IR range (for high-resolution units) and 150-250 m in the visible range, 500-600 m in the IR range (for intermediate resolution units);
-- scanning band 180-200 km and 500-700 km respectively;
-- number of spectral zones 8 and 4 in the spectral range 0.4-12.5 μm.

The periodicity of scanning (along the equator) for one space vehicle of the operational subsystem is 14-17 days with the use of multizonal units with a high resolution and 4-5 days with the use of multizonal scanning units with an intermediate resolution.

In order to study the ocean and the earth's surface plans call for radar apparatus and also scanning radiometric apparatus in the SHF range as operational tools. Plans call for the development of a system for transmission via the space vehicle of information from surface and sea platforms for the collection of data used for refining the results of remote measurements.

For the reception, processing and propagation of the data from remote measurements provision is made for organizing regional processing centers: in Moscow, Novosibirsk and Khabarovsk. The Moscow Data Processing Center will be the main center and will ensure control of operational subsystems.

These characteristics of the system are preliminary and can be refined in the course of development of the system.

Manned space stations of the "Salyut" type, meteorological satellites of the "Meteor" system, space vehicles of the "Cosmos" series and aircraft laboratories will be employed as components in the space system for the study of natural resources.

The data obtained using the created system can be used for international exchange, in the implementation of different scientific research programs, including in the course of carrying out of work under the oceanographic section of the WCRP.

United States Program

Oceanographic satellites. The objectives of the program for study of oceanic processes developed by NASA include the formulation of scientific principles for measuring oceanographic characteristics from satellites and demonstration of the usefulness of information on the ocean received from space. In the 1980's the research aspect of this program will be directed to an improvement in the understanding of the following problems: circulation and heat reserve of the oceans, movements and destruction of sea ice, biological productivity of the ocean.

Plans call for the creation of four space systems: National Oceanographic Satellite System, Topographic Experiment, Gravitational Satellite and a satellite with a side-view radar station with a synthesized aperture.

The purpose of the National Oceanographic Satellite System is a limited operational demonstration of the use of satellites for determining the characteristics of waves, near-water wind, water temperature and color, ice and currents. In addition, these data will help to solve two scientific problems: scatterometric measurements of the wind together with contact measurements of currents will be used in studying wind circulation, chlorophyll concentration, and with determination by use of a color scanner, together with shipboard data, will be used in investigating the relationship between the productivity of phytoplankton, variability of the ocean and other elements of the food chain.

The Topographic Experiment and the Gravitational Satellite are research programs. Data on the topography of the sea surface, determined by means of altimeters (Topographic Experiment), and the results of measurements of the marine geoid (Gravimetric Satellite) will be used jointly with shipboard gravimetric, hydrographic and other data for studying geostrophic circulation. In particular, it is planned that images of the sea surface and ice from a satellite carrying a side-view radar will be used for investigating the influence of the wind effect and currents on the characteristics of the ice cover on the seas.

Work will be continued for investigating improved methods for the collection of reference (polygon) information both for checking the functioning of space systems for sensing the earth in general, and also for obtaining information from the deeps for the purpose of supplementing ordinary satellite two-dimensional information on the sea surface. Work is planned on the development of means for the collection and comparison of data from contact and satellite measurements, their joint storage, compression of information, its dissemination and analysis by different users.

Meteorological satellites. In the 1980's plans call for three space systems whose information can be used in the interests of oceanography: an experiment for investigating the earth's radiation balance, a series of operational meteorological satellites (NOAA) in polar orbits and geostationary operational satellites for studying the environment (known as GOES satellites).

The purpose of the experiment for investigating the earth's radiation balance is measurement of the earth's radiation balance, including the total energy release of the sun. The experiment is based on the use of three satellites, including two of the NOAA type and one specialized satellite. It is planned that in the 1980's the NOAA satellite system will consist of 10 satellites. At present there are two satellites of this series in operation (altitude 870 km, orbital inclination 98.9°, time for intersecting the equator on the descending branch of the orbit 0730 and 0230 hours respectively). Each of the NOAA satellites has: 1) a radiometer with superhigh resolution in the optical and IR ranges, 2) a block for determining the atmospheric profile, including an IR high-resolution probe, a block for sounding the stratosphere (supplied by Great Britain) and a microwave sounding block, 3) a monitor of the solar radiation flux, 4) a system for the collection of data from surface platforms (buoys) of the ARGOS type (supplied by France) and

5) a system for automatic transmission of images. Beginning with the fifth satellite of this series they will carry an emergency search and rescue block, and beginning with the sixth -- blocks for measuring the components of the earth's radiation balance.

During 1981-1990 plans call for the use of 8 satellites of the GOES series. Now there are two operational vehicles in service (altitude 36,000 km above the earth's equator, one at the point 75°W and another at 135°W). Each satellite of the GOES series has: 1) a monitor of the flux of cosmic radiation, 2) a block for the facsimile transmission of weather maps, 3) a 12-channel scanning radiometer for the visible and IR ranges. Beginning with the fourth satellite of this series instead of the latter instrument they will be outfitted with improved radiometers capable of giving a multispectral image.

Japanese Program

The preliminary plan for 1981-1990 provides for the creation of three satellites for remote sensing of the earth. The first Japanese oceanographic satellite, the MOS-1, is intended for determining the color characteristics of sea water (for the purpose of detecting contaminations, the "red tide" phenomenon, and also for observing fishing regions) and ocean surface temperature. In addition, the satellite will be used for studying vegetation on the land. The on-board measurement complex will consist of a radiometer operating in the visible and near-IR ranges, a radiometer operating in the visible and thermal IR ranges, a microwave radiometer and a system for the collection of data from surface platforms (buoys).

The radiometer operating in the visible and near-IR range, intended for determining the color characteristics of the sea, is a four-channel scanning unit with a high resolution with electronic scanning, designed on the basis of instruments with so-called charging elements. The measurement channels are: 0.51-0.59, 0.61-0.69, 0.72-0.80 and 0.80-1.1 μm. The spatial resolution is 50 m with a scanning band of 100 km for each of the two optical systems. Each optical system consists of a Gaussian telescope and prisms separating the incident flux into two parts in dependence on wavelength and two series of charging elements consisting of 2,048 subelements. The number of signal quantization levels is 64.

The radiometer operating in the visible and thermal IR ranges, intended for determining the temperature of the sea surface, is a four-channel scanning unit with optical-mechanical image scanning. The measurement channels are: 0.5-0.7; 6-7; 10.5-11.5; 11.5-12.5 μm. The spatial resolution is 0.9 km for the visible range and 2.7 km for the IR range with a scanning band of 1,500 km. For increasing the instrument reliability each measurement channel has two radiation detectors. The number of signal quantization levels is 256.

The microwave radiometer, intended for measuring the water vapor content in the atmosphere, is a two-frequency scanning unit with conical mechanical scanning. The working frequencies are 23.8 and 31.4 GHz; the spatial resolution is 32 and 23 km respectively. The scanning band is 317 km, the radiometric response is 1°K (at 300°K), and the number of signal quantization levels is 1,024.

For work with the MOS-1 satellite and the processing of data plans call for the use of the space center Tsukuba and three stations: Matsuura, Matsuda and Okinawa.

The second Japanese oceanographic satellite, the MOS-2, is intended for the investigation of dynamic phenomena in the ocean (near-surface wind, wave heights, oceanic geoid, currents, ocean circulations, tides). The on-board measurement complex will probably consist of an altimeter, scatterometer, microwave radiometer and a system for the collection of data from surface platforms (buoys). The third oceanographic satellite, the MOS-3, will differ from the second by the presence of instrumentation for the all-weather collection of images of the sea surface (side-view radar and radiometer operating in the visible and IR ranges).

In addition to the three oceanographic satellites, Japan within the framework of the WCRP is also planning to employ its geostationary satellite GMS-2, which it is planned will be launched in 1981 to the point 140°E.

5. Development of New Means and Methods for Studying Ocean From Space

The conference noted that there is a great gap between the requirements for global information advanced by the WCRP and the modern technical possibilities for the collection of such information. This applies, in particular, to oceanographic data and meteorological information over the oceans. In many cases there is no hope for obtaining the necessary global information without the use of space observation systems. Emphasis should be on the development of on-board measurement systems, continuation of efforts for the development of methods for the processing, analysis and interpretation of space information, and the coordination of space programs for the purpose of optimum organization of observations in time and space.

In this connection, in the conference documents it is noted that in the past inadequate attention was devoted to the problems of optimum use of satellite data on a regular basis. The employed algorithms are possibly ineffective for the complete extraction of useful information from the primary data of satellite measurements. For a number of characteristics which must be determined there is an inadequate volume of synchronous surface measurements and calibrations. Satellite data must be reinforced by traditional information serving as a comparative base for ascertaining the reliability and accuracy of the space measurements; with this taken into account, in the opinion of Soviet specialists, there should be planning of future systems for remote sensing of the earth and the world ocean.

It was noted that in the carrying out of satellite measurements in the interest of oceanography within the framework of the WCRP it is necessary to organize special calibration experiments. It is possible that after some time it will become clear for all that the success of satellite measurements will require the implementation of calibrations by means of contact measurements on a regular basis. In a number of cases it will be useful to carry out a comparison of different satellite methods and also to combine experimental methods created at different institutes which mutually supplement one another.

It is recognized that for the successful realization of the oceanographic part of the WCRP it is necessary to devote special attention to the formulation and development of space methods and facilities for observational purposes intended for the global determination of temperature of the ocean surface and the near-surface wind over the ocean, measurement of rises in the sea surface relative to the geoid and determination of pressure in the near-water layer and the spectrum of surface waves.

Also noted was the importance of bringing the attention of specialists to the development of promising satellite methods, which on a global and operational basis would make it possible to determine the air-water temperature (for the Gulf Stream region an accuracy of $\pm 0.4°K$ is required) and the moisture content of the near-water layer of the atmosphere (0-20 m) with an accuracy to 0.05 g/kg, as well as the falling of precipitation over the ocean and the salinity of the water surface layer.

In conclusion it should be noted that the holding of the conference on the coordination of plans for future satellite systems for sensing the earth and oceanic experiments was an important and necessary stage in preparations for the WCRP. The mutual exchange of information and opinions made it possible for the conferees to form a sufficiently complete idea concerning the attained level and the prospects for the development of space methods and technical means for determining oceanographic parameters and characteristics of the atmosphere over the ocean. The course of the discussion indicated the enormous interest of specialists in the field of climatology, meteorology, oceanography, hydrology, as well as other scientists in related fields in the use of the potentialities of existing, and especially future satellite methods. We should also note the increasing attention to the characteristics of new noncontact methods on the part of representatives of traditional scientific fields.

The holding of this conference created the prerequisites for subsequent discussion of the problems involved in the international coordination of national plans and programs for creating individual satellites and space systems, information from which will be a necessary element in implementing the oceanographic part of the World Climate Research Program.

REVIEW OF MONOGRAPH 'AGROPHYSICAL, AGROMETEOROLOGICAL AND AGROENGINEERING PRINCIPLES OF CROP YIELD PROGRAMMING' ('AGROFIZICHESKIYE, AGROMETEOROLOGICHESKIYE I AGROTEKHNICHESKIYE OSNOVY PROGRAMMIROVANIYA UROZHAYA'), BY I. S. SHATILOV AND A. F. CHUDNOVSKIY, LENINGRAD, GIDROMETEOIZDAT, 1980, 320 PAGES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 pp 120-121

[Review by O. D. Sirotenko]

[Abstract] This book, for the first time from an integrated point of view, examines the agrophysical, agrometeorological and agroengineering aspects of yield programming. Taking into account the increasing interest in this subject, which for many specialists is associated with the introduction of physicomathematical methods into agronomy, it is probable that the book will be eagerly received. Now, as never before, there is a need for generalizing works on yield programming. The continuous increase in the number of publications on this problem has revealed a broad spectrum of possible approaches to the problem of ensuring planned yields. A great many types of mathematical models have been formulated for describing the processes of influence of weather, soil, agroengineering and other factors on yield formation, which in principle can be used in descriptive, predictive and control work in the field of plant cultivation. Meanwhile, until now there have been virtually no generalizing works guiding specialists in the development and use of the most effective approaches and models. The book consists of three parts and seven chapters. The first part gives a lengthy exposition of the fundamental problems involved in developing methods for yield programming. The second part is devoted to the modeling of processes of energy and mass exchange in the soil-agrocoenosis-atmosphere system, that is, an inventorying of the concepts and models which in principle can be used in developing automated systems for the control of technological processes in plant cultivation. The third part of the book examines the problems involved in the mathematical and technical support of automated systems for the control of technological processes in yield programming. Despite a number of shortcomings, such as some unevenness in treatment of different aspects of the overall problem, the book is the best of its kind on this subject.

SIXTIETH BIRTHDAY OF ANDREY SERGEYEVICH MONIN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 pp 122-123

[Article by specialists of the Institute of Oceanology]

[Abstract] Andrey Sergeyevich Monin, corresponding member, USSR Academy of Sciences, director of the Institute of Oceanology, marked his 60th birthday on 2 July 1981. He is characterized by an astonishing work capacity, being the author of hundreds of articles and monographs; he is the chairman or a member of a great many commissions, the director of a seminar on geophysical hydrodynamics, has been a participant or director of many sea expeditions and an investigator of the sea floor. The principal stages in his career have been as follows: some 7 years at the Central Institute of Forecasts, 15 years at the Institute of Atmospheric Physics, 16 years at the Institute of Oceanology. In his years at the latter institute he was most responsible for publication of the ATLAS OKEANOV (Atlas of the Oceans)(1980). Recently he was editor of the fundamental 10-volume publication OKEAN (The Ocean), which summarizes the most up-to-date information concerning the oceans: on the history of development of the oceans, the course of their natural evolution, their geology and geography, chemistry and biology, on the dynamics of currents, wave and turbulent processes. His range of scientific interests is astonishing: from flying saucers to evaluation of global productivity of the oceans. His principal monographs (some with co-authors) have been: STATISTICHESKAYA GIDROMEKHANIKA (Statistical Hydromechanics), 2 volumes, 1965, 1967; PROGNOZ POGODY KAK ZADACHA FIZIKI (Weather Forecasting as a Problem in Physics), 1969; VRASHCHENIYE ZEMLI I KLIMAT (The Earth's Rotation and Climate), 1972; IZMENCHIVOST' MIROVOGO OKEANA (Variability of the World Ocean), 1974; ISTORIYA ZEMLI (History of the Earth), 1977; ISTORIYA KLIMATA (History of Climate), 1979; OKEANSKAYA TURBULENTNOST' (Oceanic Turbulence), 1981. Figures 1.

SEVENTIETH BIRTHDAY OF SEMEN SEMENOVICH GAYGEROV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 pp 123-124

[Article by personnel of the Central Aerological Observatory]

[Abstract] Professor Semen Semenovich Gaygerov, doctor of geographical sciences, head of the Laboratory of Meteorology of the Upper Atmosphere at the Central Aerological Observatory, marked his 70th birthday on 15 October 1981. Beginning his work in the Hydrometeorological Service in 1929, he progressed from observer at a meteorological station to a leading specialist in the field of experimental aerology and synoptic meteorology. He is now well known in the USSR and abroad. He was one of the organizers of the Central Aerological Observatory in 1940 before serving as a meteorologist in the armed forces. After the war ended he participated in unique investigations with balloons, making possible a quantitative evaluation of the principal meteorological parameters of moving air in the troposphere. As an active participant in the IGY, Gaygerov during 1955-1956 carried out aerometeorological investigations on the drifting station "Severnyy Polyus-4," and in 1956-1958 he participated in the Second Soviet Antarctic Expedition. The results of these studies were generalized in a number of articles and monographs and were included in the ATLAS OF ANTARCTICA. Beginning in 1964, Semen Semenovich made studies of macroscale processes in the high layers of the atmosphere. He headed a number of expeditions at sea on which rocket measurements were made and with use of data from thermal sounding from satellites. He directed work at the Central Aerological Observatory for developing a new standard atmosphere for the layer 30-80 km. The results of the mentioned studies were a component part of the COSPAR Reference Atmosphere of 1972. During 1971-1972 Gaygerov participated in the 16th Soviet Antarctic Expedition, heading the aerometeorological detachment. At that time investigations of atmospheric circulation were made to an altitude of 90 km, the results being included in the monograph VOZDUSHNYYE TECHENIYA V MEZOSFERE ANTARKTIKI (Air Currents in the Antarctic Mesosphere) (1975). S. S. Gaygerov has published more than 100 scientific studies, including six monographs, which have received recognition in both the USSR and abroad. His book AEROLOGIYA POLYARNYKH RAYONOV (Aerology of the Polar Regions) has been translated into English. Figures 1.

SIXTIETH BIRTHDAY OF NIKOLAY GAVRILOVICH LEONOV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 pp 124-125

[Article by specialists of the USSR Hydrometeorological Scientific Research Center]

[Abstract] Nikolay Gavrilovich Leonov, candidate of physical and mathematical sciences, head of the Short-Range Weather Forecasting Division of the USSR Hydrometeorological Scientific Research Center, marked his 60th birthday on 7 August 1981, together with the 40th anniversary of his scientific work. After graduating in 1943 from the Higher Military Hydrometeorological Institute of the Red Army, he was sent to the Administration of the Hydrometeorological Service of the Far Eastern Front, where he participated in hydrometeorological and forecasting work. After the war N. G. Leonov went to work at the Central Institute of Forecasts, where he advanced through the ranks to be deputy director. He is an outstanding specialist in different fields of synoptic meteorology. Between November 1955 and August 1957 he participated in the First Soviet Antarctic Expedition, data from which he generalized and published in three scientific studies. While deputy director of the USSR Hydrometeorological Center, Nikolay Gavrilovich did much work directed to improving the collection, processing and preparation of routine materials and introduction of advanced forecasting methods for the analysis and forecasting of weather. At the USSR Hydrometeorological Center he was the first to prepare global maps of cloud cover on the basis of observations from meteorological artificial earth satellites. He headed a section in the World Weather Service and directed the section for the analysis of world weather and data dissemination. N. G. Leonov did much work along the lines of international technical cooperation in the field of synoptic meteorology and is widely known among foreign scientists. He occupied a series of responsible posts in the WMO Secretariat. He was Vice President and later President of the WMO Commission on Synoptic Meteorology. For many years Nikolay Gavrilovich headed a working group on codes at the USSR Hydrometeorological Center and devoted much attention to the development of new and improvement of existing international meteorological codes. Figures 1.

AT THE USSR STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 p 125

[Article by V. N. Zakharov]

[Text] In accordance with a decree of the Board of the USSR State Committee on Science and Technology, in April 1981 the Valday Scientific Research Hydrological Laboratory imeni V. A. Uryvayev of the State Order of the Red Banner of Labor Hydrological Institute was transformed into the Valday Affiliate of that institute.

Stepan Fedorovich Fedorov, doctor of geographical sciences, has been designated director of the Valday Affiliate of the State Hydrological Institute.

In connection with the creation of the affiliate its missions have been expanded considerably in comparison with those performed earlier by the Valday Laboratory.

CONFERENCES, MEETINGS, SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 pp 125-128

[Article by M. A. Butuzova, A. A. Zhelnin and N. A. Zaytseva]

[Text] A session of the Scientific Council on the Problem "Artificial Modification of Hydrometeorological Processes" of the State Committee on Hydrometeorology and Environmental Monitoring was held during the period 22-23 April at the Central Asian Regional Scientific Research Institute imeni V. A. Bugayev (Tashkent).

About 25 members participated in the work of the Council, as well as specialists of the Artificial Modification Division of the Central Asian Scientific Research Institute.

The forum of scientists was opened by N. N. Aksarin, director of the Central Asian Scientific Research Institute. I. I. Burtsev, head of the Administration on Use of Artificial Modification in the National Economy, presented appropriate introductory remarks from the State Committee on Hydrometeorology and Environmental Monitoring. He noted the principal problems facing the institutes of the State Committee on Hydrometeorology and Environmental Monitoring in the field of artificial modification of precipitation during the current year and during the Eleventh Five-Year Plan.

In accordance with the work plan for the Council for 1981-1982, the session of the Scientific Council discussed programs for regulating precipitation in different regions of the Soviet Union. It was noted in the reports and communications that during recent years the institutes of the State Committee on Hydrometeorology and Environmental Monitoring have carried out a considerable volume of investigations in the field of artificial increase in precipitation in lowland and mountainous regions of the country.

The Ukrainian Scientific Research Institute has developed and presented to the State Committee on Hydrometeorology and Environmental Monitoring a method for the artificial augmentation of precipitation in the lowland regions. Beginning in the winter of 1980/1981 an experiment was initiated for increasing winter precipitation over an area up to 500,000 hectares for the purpose of evaluating the modification effect. Experimental studies are being carried out for an artificial increase in precipitation in the basin of the Iori River under a program bearing the same name. Investigations of the possibilities of organizing work for obtaining additional precipitation in Central Asia and the Lower Volga have been initiated; beginning in 1980 regular work has been carried out on an artificial increase in precipitation in the basin of Lake Sevan. There has been further development of work on methods for statistical evaluation of the results of experiments for an artificial increase in precipitation. A statistical model of the quantity of precipitation is now being developed.

However, the programs for work on the artificial increase in precipitation reported at the Scientific Council require further improvement and especially with respect to the planning and evaluation of the effectiveness of the experiments. It was noted in the course of the discussions that special attention should be devoted to the development of methods for evaluating the physical and economic effectiveness of artificial modification; there was emphasis on the need for development of investigations in the field of physics of the processes of natural cloud and precipitation formation and artificial modification of these.

A brief communication was presented on the possibility of using aircraft generators, pyrotechnic shells and rockets, as well as artillery shells, in work for increasing precipitation. On the basis of these computations it was established that in order to increase precipitation from stratiform clouds not one of the known antihail techniques is suitable. Most of these techniques are far from optimum even for the modification of cumulus clouds.

In the communications there was repeated emphasis on the inadequate outfitting of projects with the necessary technical apparatus, including for the introduction of reagents, as well as instruments for a detailed investigation of the microphysical characteristics of clouds, especially for measuring the concentration of small crystals, which makes difficult the carrying out of investigations under programs at the modern level.

The results of discussion of the reports determined the fundamental points in the resolution adopted by the Scientific Council. It was noted in the resolution that in implementing the planned programs for increasing precipitation it is necessary to devote particular attention to the planning of experiments with a possibility of evaluating the effects. The resolution noted the need for developing investigations in the field of physics of processes of natural cloud and precipitation formation and artificial modification of them, experimental investigation of the microphysics of the solid phase of clouds, and improvement in statistical methods for evaluating the effectiveness of an artificial increase in precipitation.

It was deemed desirable that particular attention be devoted to the development of an expanded program of work on the problem of an artificial increase in precipitation for the period up to 1990.

According to the approved plan, at the next session of the Scientific Council at Nal'chik there will be a discussion of the status of scientific investigations and the results of practical work on the problem of prevention of hail in the USSR and the socialist countries and also work on hail prevention carried out in the United States.

In 1982 plans call for two sessions of the Scientific Council in Leningrad and Sevan. The first will be devoted to an analysis of the status and prospects of remote methods for investigating cloud media and precipitation. At the second session there will be a discussion of the research programs carried out at the field experimental bases of the State Committee on Hydrometeorology and Environmental Monitoring.

M. A. Butuzova

An international conference on the preliminary results of the FGGE and the macro-scale aspects of its monsoonal experiments was held during the period 12-17 January at Florida State University (Tallahassee, Florida). It was organized by the American Meteorological Society under the direction of the WMO. This was the second international forum of scientists devoted to a discussion of the preliminary results of the FGGE. The first conference of this type was held in June 1980 at Bergen (Norway). At the conference at Tallahassee there were 104 reports from 10 countries: United States (53), India (15), USSR (12), France (8), Australia (5), Japan (2), Chinese People's Republic (2), Cameroon (1), Malaysia (1). The conference program included 13 sessions; 14 requested reports were presented.

Session 1: Review of international results of FGGE. Six reports were presented, of which 4 were requested. In a review report by V. Suomi (United States) information was given on the operation of meteorological satellites during the FGGE period, there was discussion of work on the collection of data from automatic platforms (buoys, balanced probes) with the use of artificial earth satellites and examples were given of forecasts for four days in advance, taking into account the wind reconstructed on the basis of satellite photographs. L. Bengtson (Great Britain) analyzed FGGE data on global mean daily forecasts and noted the good results of forecasts for five days in advance in the southern hemisphere. It is anticipated that the deterioration of the observational network after the FGGE will reduce the quality and shorten the advance time of forecasts, especially in the tropics and in the southern hemisphere. M. Halem (United States) told about the use of data on wind and temperature profiles obtained using artificial earth satellites. In a review report by T. Nitta (Japan) the author gave the preliminary results of the FGGE and MONEX. Data from geostationary artificial earth satellites are used in studying the spectrum of the development of cloud cover; maxima with periods of 2-3, 4-5, 14 and 48 days are discriminated; the maximum amplitude of the 48-day variations is noted in the central part of the Indian Ocean. Results of an analysis of the profiles of wind divergence in comparison with the GATE period are presented. In the requested report of K. Miyakoda, et al. (NOAA, United States) there was a discussion of the results of four-dimensional analysis of FGGE data carried out at the Princeton Geophysical Fluid Dynamics Laboratory.

Session 2: Contribution of FGGE data. The requested report of P. Julian (NCAR, United States) described a system of observations in the tropics during the FGGE period and gave a qualitative and quantitative analysis of level III-b data. F. Mosher (United States) cited the results of a comparison of wind fields obtained using data on cloud cover from different artificial earth satellites and from radiosondes; the error varied in the range 2-3 m/sec. G. Mills (Australia) demonstrated the results of a numerical experiment for objective analysis and forecasting for 24 hours in advance in the Australian region during the second special observation period (SOP-II). He pointed out that for a complete system of "analysis-forecasting" equations the FGGE observation system was adequate but with the usual system a complete analysis is impossible.

Session 3: Diagnosis on the basis of FGGE data. Five reports were presented by the United States (Goddard Atmospheric Sciences Laboratory, Wisconsin and Maryland Universities). An analysis of FGGE data made it possible to establish the presence of stationary Rossby waves in the atmosphere over the Pacific Ocean in the zone 20-40°S with a wavelength of about 120° in longitude in the air flow beyond the

Andes. A detailed analysis was made of the transport of energy on a planetary scale and the spatial and temporal distribution of nonadiabatic energy "gains" and "losses." It is asserted that the energy sources are situated in the region of Indonesia, the Philippines and Southeast Asia, whereas the losses occur in the Sahara region and in the eastern parts of the subtropical anticyclones. There is a seasonal movement of sources from one hemisphere to the other.

Session 4: Winter MONEX -- Planetary Scale. The reports analyzed the wind field and atmospheric temperature and energetics during the period of winter MONEX. T. Murakami (United States) analyzed the orographic influence of the Tibetan Plateau on atmospheric circulation in Asia during the winter monsoon. A westerly flow at the 500-mb level, bending around Tibet, is discriminated; its southerly branch is characterized by the presence of a jet stream. At the 200-mb level there are short-period (3.5-5.5 days) eddies observed for the most part over China and long-period (12-20 days) stationary disturbances over India. P. Webster (Australia) described the mechanism of macroscale circulation of the winter monsoon. He defined two critical moments: 1) limitation of the field of nonadiabatic heating and the jet stream caused by it in the northern part of Asia; 2) as a result of spatial-temporal characteristics of nonadiabatic heating in the low latitudes the total heating is directly related to the dynamics of the system, whereas in the high latitudes this relationship is weak. A theory of low-frequency modulation of macroscale circulation of the winter monsoon is formulated on this basis.

Session 5: Summer MONEX -- Planetary Scale. Eleven reports were presented, devoted to an analysis of atmospheric circulation in the premonsoonal and monsoonal periods and attempts to clarify the reasons for phenomena and finding prognostic criteria. The reports of G. Young (United States) and M. Debois (France) analyzed data from the geostationary satellite GOES together with data from radiosondes and equal-altitude balloons. The mean fields of circulation were obtained and the eddy and divergence fields were computed. D. Cadette (France, United States) analyzed the influence of middle-latitude disturbances in the southern hemisphere on the low jet stream over eastern Africa and established a correlation between interhemispherical interactions and monsoonal activity over India. S. R. V. Raman (India) demonstrated a correlation between middle-latitude westerly transfer over Asia and the southwesterly monsoon. R. Pasch (United States) revealed the relationship between the process of setting-in of the monsoon over India and changes in tropical circulation on a planetary scale. P. R. Pisharoti (India) formulated a new theory of the development of the summer monsoon; it relates the development of the monsoon to the conditions for the transport of heat across 30-40°N from the equatorial to the polar latitudes in the course of the preceding winter. In other words, monsoonal anomalies must be expected as a result of anomalous energy transfer into the polar regions during winter. F. Ardana (United States) demonstrated the relationship between monsoonal interruptions and the westward advance of 10-20-day waves. E. Kang and T. Sharif (United States) presented a multiple regression method for the setting-in of the monsoon and the total quantity of precipitation for an advance time of about two months.

Session 6: Summer MONEX -- Radiation Heat Sources. An analysis was made of the radiation characteristics of the atmosphere on the basis of satellite, aircraft and radiosonde data. A study was made of the influence of a high surface albedo and atmospheric aerosol. A requested report by S. Cox (United States) gave the results of a multisided analysis of the radiation fluxes over the Arabian Peninsula. A total cooling of the layer from the surface to 840 mb by 2.5°C/day and heating of the layer 840-695 mb by 0.2°C/day are found.

Session 7: Summer MONEX -- Numerical Modeling. The requested report of P. Das (India) was devoted to an experiment with a three-level numerical model of regional forecasting based on primitive equations. The requested report of T. Krishnamurti and I. Ramanathan (India) by means of a three-dimensional analysis investigated the state of the atmosphere prior to the bursting of the monsoon. Other reports described numerical experiments with regional forecasting models. The variability of circulation is investigated.

Session 9: West African Monsoonal Experiment (WAMEX). In a requested report S. Mbele-Mbong (Cameroon) described a system of observation stations in the tropical zone of Africa and discussed their operation during the FGGE period. Three reports from France and one from Nigeria described the results of observations during the WAMEX period.

Session 9: Summer MONEX -- Oceanographic Results. In a requested report F. Schott (United States) described the results of oceanographic observations in the Somali Current in connection with the setting-in of the summer monsoon. In other reports (United States, India, USSR) an analysis was made of the upwelling phenomenon, the distribution of water surface temperature and the characteristics of water circulation in the Arabian Sea.

Session 10: Winter MONEX -- Circulation and Convection. Reports from the United States, Australia, USSR, Malaysia and China gave the results of an analysis of meteorological conditions on the basis of data from satellites, aircraft and radiosondes. A study was made of the diurnal variation of convection in the South China Sea and on Borneo. The characteristics of development of cloud clusters were described. An analysis of the cold intrusion of 10-12 December 1978 was presented.

Session 11: Summer MONEX -- Lows; Session 12: Summer MONEX -- Circulation; Session 13: Summer MONEX -- Problem of Setting-in of Monsoon. At these sessions there was a discussion of different aspects of study of the summer monsoon: the dynamics of the boundary data using data from equal-altitude balloons (France) -- the results of the BALSAMINE experiment; numerical modeling of circulation, including jet streams at different levels; characteristics of the formation and development of lows in the Bay of Bengal and the possibilities of their prediction; changes in meridional circulation and phases of the summer monsoon; aspects of interhemispherical interactions, etc. An analysis was made of the transfer of air masses and water vapor, structure of convective cloud cover, etc.

The conference graphically demonstrated the high quality, completeness and uniqueness of the mass of FGGF data, making it possible to carry out a more complete analysis and prediction of circulation, earlier impossible in some regions. Particular attention was given to the work region and the results of the winter MONEX. The FGGE materials indicated that during winter the region of the Malaysian-Indonesian archipelago is a special territory of the equatorial zone where there is maximum interhemispherical and interlatitudinal exchange, having great importance for the circulation in the extratropical latitudes. FGGE results are being used extensively now for the planning and coordination of new investigations of atmospheric circulation both on a glob.l scale and in individual regions.

A. A. Zhelnin and N. A. Zaytseva

OBITUARY OF TAISIYA VASIL'YEVNA POKROVSKAYA (1900-1981)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 10, Oct 81 p 128

[Article by specialists of the Order of the Red Banner of Labor Main Geophysical Observatory imeni A. I. Voyeykov]

[Abstract] Professor Taisiya Vasil'yevna Pokrovskaya, doctor of geographical sciences, one of the outstanding climatologists of the Soviet Union, died on 4 April 1981. After graduating from Leningrad State University in 1924, she began her work at the Main Geophysical Observatory in 1925, where she worked for 56 years. After defending her candidate's dissertation in 1938, Pokrovskaya became a senior scientific specialist in the climatology division and later section head and division head for the division of synoptic research and the division of world climatology. The scientific activity of T. V. Pokrovskaya was directed to the development of Soviet climatology and long-range weather forecasting. In 1934 she prepared a climatic description of drift of the "Chelyuskin." Later this work was developed in her monograph KLIMATICHESKOYE OPISANIYE SEVERNOGO MORSKOGO PUTI (Climatic Description of the Northern Sea Route). Then she published a major work on the climate of Central Asia. During the war Taisiya Vasil'yevna took an active part in climatological support of operations of the army and air force. She proposed a synoptic-climatological method for long-range forecasts. In the monograph SINOPTIKO-KLIMATOLOGICHESKIYE I GELIOGEOFIZICHESKIYE DOLGOSROCHNYYE PROGNOZY POGODY (Synoptic-Climatological and Heliogeophysical Long-Range Weather Forecasts) (1969) T. V. Pokrovskaya generalized the results of long-term studies. During recent years her scientific activity was devoted to study of the change in climate, study of the conditions of the formation of droughts and the development of methods for predicting them on the basis of allowance for circulatory and heliophysical factors. The publications of T. V. Pokrovskaya are well known among Soviet and foreign scientists.

5303
CSO: 1864/4

- END -